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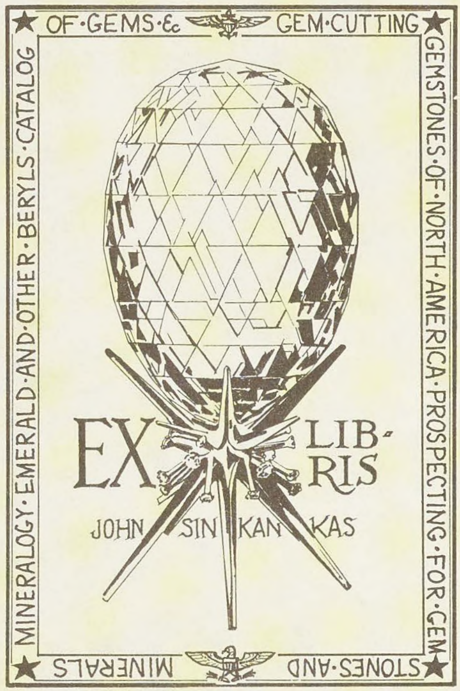
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COMMON THINGS SERIES
Edited by Prof. J. Arthur Thomson, LL.D.

COMMON STONES

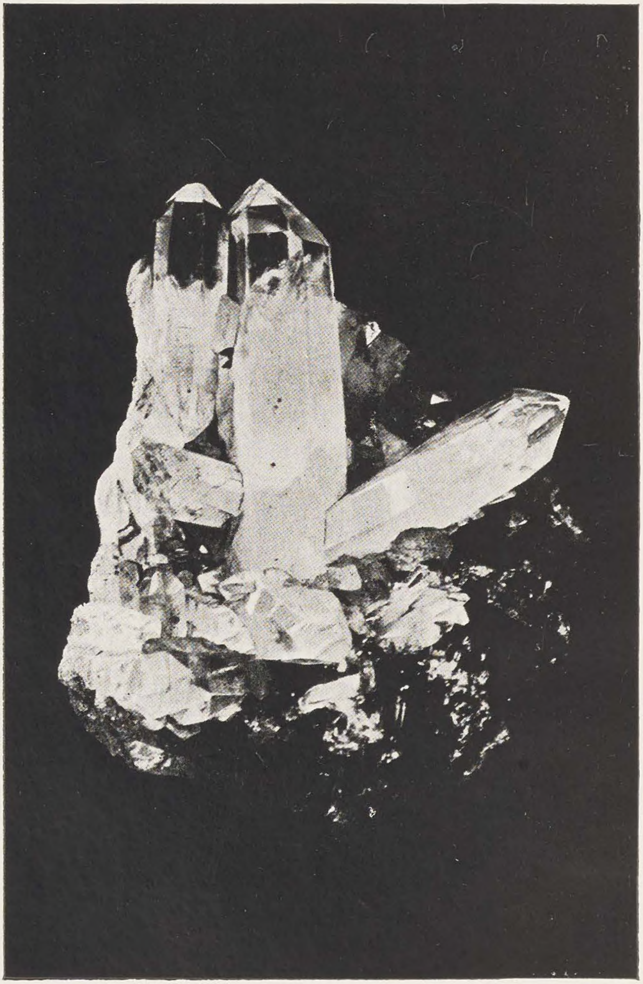

Fig. 1. Quartz (Rock Crystal).

Frontispiece.

COMMON STONES

UNCONVENTIONAL ESSAYS IN GEOLOGY

By
GRENVILLE A. J. COLE, F.R.S.
Author of "Open-Air Studies in Geology,"
"The Changeful Earth," "Rocks
and their Origins," etc.

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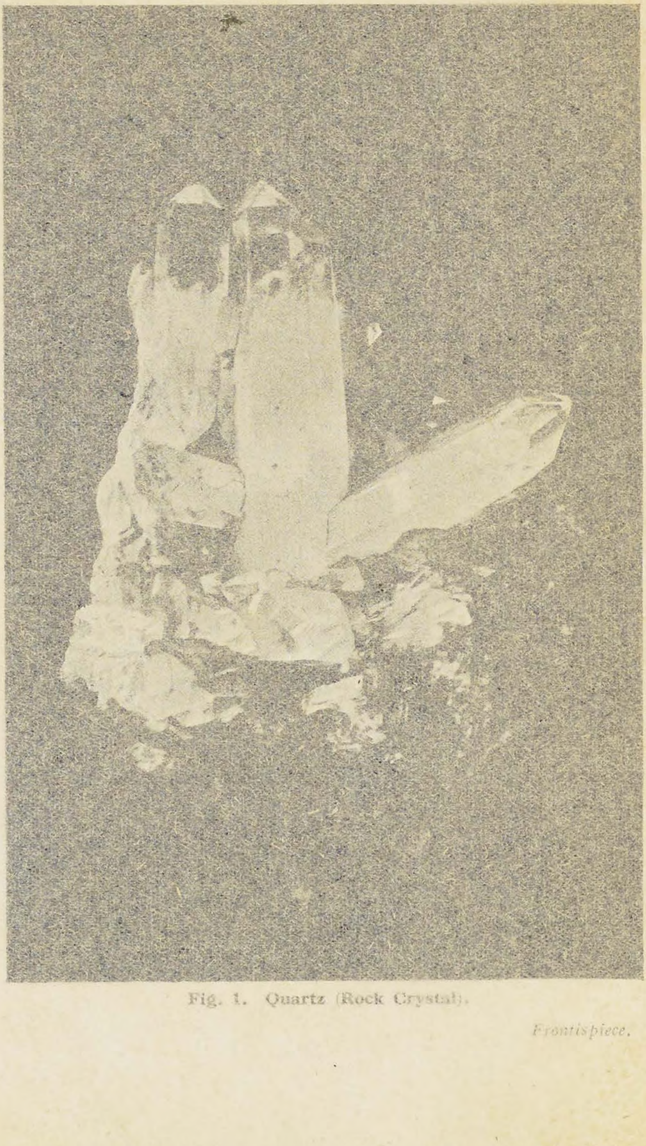

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TO

GEORGE FLETCHER

THIS LITTLE BOOK IS

AFFECTIONATELY INSCRIBED

CONTENTS

ILLUSTRATIONS

(*The landscape illustrations are from photographs by the Author. The photographs of specimens are by Mr. T. Price*).

CHAPTER I

THE STUDY OF STONES

WHEN Professor J. A. Thomson was so kind as to suggest that I should write this little book on Common Stones, I hesitated for some time in view of what had been written in the past. There are many classical works on rocks, and the student is now well provided. For those who want to know the results of modern methods of research, what could be better or more convenient than the two volumes of a *Text-book of Petrology*, by F. H. Hatch and R. H. Rastall ?

Yet it was clear that in these pages there was to be no question of a text-book. Common animals and common plants make a very natural appeal to us as living creatures ; but they depend for all the welcome delicacy of their growth and movement fundamentally on mother earth. Should not common stones, the very substance of the earth, find a first place in a general survey of things natural ? On this ground the older naturalists were also pioneers in mineralogy.

I have before me C. S. Sonnini's edition of Leclerc de Buffon's *Histoire naturelle générale et particulière*, year viii. of the Republic ; the section on minerals runs from the eighth to the sixteenth volume, and was then placed for the first time in the position marked for it by

Buffon. In his opinion, since living things dwelt upon the earth, it was right that minerals, which included also rocks, should be studied before animate nature. Without claiming that any rigid sequence should be pursued in what is now called "nature-study," it is reasonable to suppose that some knowledge of the principles of chemistry and physics forms a general groundwork in the curriculum of modern schools. A certain acquaintance with the elementary stuffs that form the earth, with the forces that act on them, and with the only rational system of weights and measures, decreed in Paris during the stormy days of 1790–95, may now be presumed in those who care at all for Nature.

On this basis we may converse on common stones, and the common stones will carry us away from the vexatious problems of our daily life, just as the regular monthly issue of Buffon's volumes kept up Sonnini's heart in an age "que le tourbillon rapide des passions ambitieuses et dévoratrices . . . sembloient ne devoir marquer que du sceau du malheur et de la destruction" (vol. vii., p. 351).

The studies of René Just Haüy, of Alexandre Brongniart, of P. Louis Cordier, in those passionate years remain. They survive the crash of empires, for they are concerned with things far greater than our human lives. The division of our appreciations, the arbitrary partition of what we seek in learning, into sciences and humanities is intellectually out of date. Our common interest and common joy in common things are the surest links that bind us to our fellow-men. Enquiry in the fields of science is an appeal to enterprise, a claim on reason, and above all a test of mere opinion against inexorable truth. Surely these are to be counted

as humanities. We take pleasure in the earth because we are citizens of the earth; and so let us proceed to common stones.

In a general introduction such as this, without formality or classification, we are free to take things much as we find them round our homes. If we question the rocks, we also question those who live among them. The human settlement owes much to the qualities of the stone. We bring to the understanding of the homeland all that we can gather in our travels; if we do not grasp the local conditions clearly, it is often because we have failed to take a larger scope.

In these pages an attempt is therefore made to connect the stones with the features of the country where they may be found, and naturally localities known to the writer are used as first examples. Recent and even tentative explanations of rock-structure have been mentioned of set purpose. Science grows with the arrival of new thinkers, quite as much as with new experimental means. The latter, indeed, are commonly dependent on the former. Where I have given authors' names, they are merely by way of illustration; I would gladly have quoted from the scientific literature of the world. We start on journeys that never know completion; we touch on essential problems of land and air and sea; and the reader, if he pleases, may choose his guides for the way that stretches onward. In such pursuits, in France, in Italy, in Austria, in Germany, in Yugoslavia, in the great continents of east and west, he will meet his fellow-workers and he will always meet them as his friends. Suffice it for the present that he starts upon the path; may I hope that the first few steps will be our mutual pleasure?

COMMON STONES

When entering on the study of stones, we are soon impressed by their likeness, class by class, throughout immeasurable time. Yet their relative ages is often a matter of much interest. Is this stone very ancient, or is it, perhaps, contemporary with man's arrival on the earth ? How far may we look back and yet trace the rain falling and the winds beating and the white surf rolling on the shore ? Does the red sand on Halidome Hill represent the barren margin of the sea that gave soft burial to its " ships of pearl " in the clays of Nether Marshfield ? Or are these two deposits separated, in their physical history, by thousands or even millions of years ?

William Smith, of Churchill among the Cotswolds, showed how these questions might be answered, when he published the four parts of his *Strata Identified by Organized Fossils* in 1816–19 (see T. Sheppard, *William Smith, his Maps and Memoirs*, Brown & Sons, Hull, 1920, and G. Cole, *The Changeful Earth*, Macmillan, 1911). Successive groups of animals and plants mark out successive strata, and the discovery of a sufficient range of fossil remains, or sometimes even of two or three highly characteristic forms, enables us to place a stratum on its horizon in the long history of living things.

The names now adopted for the great " periods " of geological time, and for the " systems " of strata corresponding with them, are given here for reference, since it will be convenient to use them now and again in connexion with the stones described.

GROUP AND ERA.	SYSTEM AND PERIOD.
QUARTARY (OR QUATERNARY) . .	*Recent.*
CAINOZOIC (OR TERTIARY)	*Pliocene.*
	Miocene.
	Oligocene.
	Eocene.
MESOZOIC . . .	*Cretaceous.*
	Jurassic.
	Triassic.
PALAEOZOIC . . .	*Permian.*
	Carboniferous.
	Devonian.
	Gotlandian (or *Silurian*, or *Upper Silurian*).
	Ordovician (or *Lower Silurian*).
	Cambrian.
PRE-CAMBRIAN . .	Fossils too scarce to allow of the establishment of systems.

It is convenient to remember that the fauna recorded from Cambrian and Ordovician times is invertebrate. Fishes appear with certainty in the Gotlandian period and dominated the Devonian seas and lakes. Amphibia were well developed by the close of the Carboniferous period, and the rapid progress of the generalized reptiles of Permian times led throughout the Mesozoic era to an overpowering empire of reptiles of specialized and often gigantic forms. The first recorded bird is Upper Jurassic, and is clearly a descendant of the reptiles.

Mammals of monotreme and marsupial type are

known from Upper Triassic strata onwards; but the mammalia did not prevail on the earth until they were freed from reptilian oppression in the Eocene period. Their rapid development in all branches of activity, on land and sea, and even in the air, rivalled that previously seen among the reptiles. Lemuroid precursors of the Primates, the group to which we ourselves belong, are traceable as far back as Eocene times, and Man becomes the prominent and controlling feature of the Recent period. His spread, however, was for some time checked by the cold "Glacial" epoch, which allowed ice to cover large areas that enjoy a temperate climate at the present day.

It is high time now that we ceased from talking and went to seek our common stones. The following chapters have no definite arrangement. They were written much as the subject-matter came to mind, and, if any art is shown, it is in the avoidance of classification. Each stone, with its uniformity or diversity of texture, suggests a problem in earth-history. Patient research and keen observation lie at the root of explanations; we may even find ourselves in college corridors, among those who say unto us, "Are you B.A., or peradventure you would be B.Sc.?" Let us entreat these enquirers courteously, for much wisdom may be gathered from them; without it we pass as mere sightseers through the parks of all the world. Armed with it, we may walk there gladly, where the sway of the leaves reveals the rock and the water thunders in the clefts. There in the woodland of adventure, or high against the sunlight on the airy edge, we shall know that the stones of the earth are the place of sapphires, and it hath dust of gold.

CHAPTER II

CRYSTALS IN THE ROCKS

WE are out on the hillside in the first free day of the spring, where every one who loves Nature ought to be, and we have come in our climb to one of those grassy ledges from which a cliff goes up sheer, offering very doubtful foothold. The expansion of water into ice in the crevices during frost, and also the general attack by wind and weather, have showered down fragments from the wall of rock.

These lie as stones upon the lower slopes; but we can easily find a comfortable place between them. We sit down and fling one of these stones towards the rough pasture far below—not a large one, for from this height it might easily kill a sheep. As the stone leaves the hand, the sunlight catches on something in it that gives a sudden gleam. We pick up another, and notice in it little plates that shine and glisten. Some of them have a fairly regular outline, with six sides; they have a flaky structure, and thin layers can be easily peeled away from their flat surfaces. We look from the stone to the rock-mass from which it came.

The rock shows along all its exposed surfaces specimens of the same gleaming flaky substance. This substance is thus an essential constituent of the mass. A stone is,

after all, only a sample of a rock, and the two terms may often be used in the same sense.

As we move on and examine the cliff-face, we come to a crevice, where the rock must have cracked apart very long ago. A hard white substance, resisting all attempts to scratch it with a knife, fills up most of this crevice; but here and there hollows have been left, as if the material had been brought in by water, perhaps in a state of solution, and had shrunk as it dried and settled down.

One of these hollows catches our attention. It has a green stain in it, due, as a chemist would tell us, to a trace of some salt of copper; we are here, in fact, dealing with a common type of mineral vein.

But what especially attracts us are several clear forms jutting out from the walls of the hollow, like little prisms cut out of glass, but as hard as the white mass from which they spring (Fig. 1). These are *crystals*, "rock-crystals," the objects that were named *krustalloi* by the ancient Greeks,[1] from the notion that they were an unmeltable form of ice. From them the name crystal has been given to every natural product that has a definite geometrical form, made up by the grouping of surface-planes.

When we say "natural product," let us remember that there is no such thing as an artificial crystal. If chemical substances assume regular crystalline forms before our eyes in a laboratory, our artifice has merely brought the right materials together under the right conditions. Natural forces, and not any human shuffling, have grouped the particles so as to build up the crystal.

And here, hidden away for ages in the earth, and

[1] By the geographer Strabo, for instance, at the opening of the Christian era.

revealed by the weathering back of the rock-mass, the crystalline constituents of the rocks have come to light. We are face to face with *minerals*, which in these cavities, where they developed with a certain freedom, have been able to assume a crystal-form.

The six-sided plates in the main mass of the rock clearly show a tendency to crystallize ; they have succeeded in this to some extent, but have been hampered by other materials round about them. Their external forms, and their internal properties also, differ from those of the transparent little prisms in the veinstone, and we are ready to recognize them as distinct mineral species. The chemist, if we gave them to him for analysis, would bear us out in this. Why do we call them minerals and not merely stones ? That is a very proper question.

The *stones* of the earth differ from the minerals of the earth, since they are made of minerals and have no fixed chemical composition of their own. The old writer who said that they were " the place of sapphires " recognized that the sapphires were something different from the stone.

The stones on our hillside may be traversed by cracks, disposed with some show of regularity, which give their fragments smooth surfaces that resemble those of crystals ; but the angles at which these surfaces of fracture meet have nothing of the beautiful constancy that is revealed when we measure crystal-forms. A mass of crystallized calcium carbonate, for example, that is, a large crystal of the mineral known as calcite, breaks when struck with a hammer along three sets of planes. These are the *planes of cleavage* of the crystal, and the angles between them, measured perpendicularly to the edges

formed by their intersections, are always exactly 105°5′ or the supplementary angle 74°55′. Something in the grouping of the fundamental particles of which the crystal is composed determines these planes along which fracture so regularly occurs.

No such regularity marks the fracture of an ordinary stone. The planes of *rock-cleavage*, for example, that are so well exhibited in slate (p. 117), and that give this material its commercial value, cut the other surfaces of fracture at various angles. Even the remarkable hexagonal forms assumed by parts of lavas during cooling, which are popularly known from the examples at the Giant's Causeway in the county of Antrim, fail to secure mathematical constancy of angle. Their surfaces break across the true crystals that have developed in the rock, and they are due to shrinkage and not to fundamental structure.

A stone may consist of one mineral material only ; but the grouping of the mineral particles will record the history of the stone. More often, several distinct minerals are aggregated to form the stone ; their particles may be worn and rounded, and bound together by some natural cement ; or they may be intergrown and interlocked, with no regular surfaces of junction ; or one mineral substance, like the plates in our rock-face, may have developed before the rest, securing its own characteristic crystal-outlines, and leaving the other materials to form mineral combinations in such space as they could find in the interstices.

Sometimes the mineral matter remains uncrystallized, that is, its chemical components have been unable to come into the right positions during the somewhat hurried consolidation of the stone ; we may thus even have a natural glass, or a duller rock, the materials

of which are said to be "amorphous," tbat is, without characteristic shape.

There are, however, very few cases in which mineral matter remains amorphous. Two liquids may be mixed together during a chemical experiment in a laboratory, and a precipitate appears, in the form of a fine powder, which gathers at the bottom of the vessel. Although this has been formed almost instantaneously, it rarely consists of uncrystalline material. The fact that it has formed at all implies a new grouping of the substances that were present in a state of solution in the liquids, and grouping in the solid form implies a pull of particle upon particle, an arrangement that makes for rigidity, imparting a uniform structure to the compound particle, the piece of the new substance that is thus built up. The granules produced may not show a crystal-form upon their surfaces; but in the vast majority of cases they will actually consist of crystals or of aggregates of crystals. Often each particle of the precipitate, growing as it sinks through the liquid from which it forms, is a perfect crystal, with a characteristic shape, determinable on examination with a microscope.

We may go even farther. Whatever the external form may be, the use of polarized light enables us to say that these minute bodies possess, in the great majority of cases, the internal structure of crystals. Polariscopes were formerly attached to microscopes in order to show pleasing effects of colour when crystalline substances were exhibited at conversaziones, for the admiration of those who glanced at them casually and then passed on to hear the music. They are now, however, an adjunct to every microscope used by workers in chemistry, physics, mineralogy, or geology. The object examined

with the aid of the polariscope must of course allow light to pass through it; in the case of a rock, we can grind it down until it is sufficiently thin; many of the minerals, in fact, can in this way be rendered absolutely transparent. There is one group of crystals, with a very high type of symmetrical arrangement in their interior, which has no effect on what we call polarized light. In most cases, however, the light that has passed through the instrument called the polarizer, which merely provides light-rays vibrating in one particular direction, is divided, on passing through the crystal, into two sets of rays with different properties.

By the use of a second instrument called the analyzer, which constitutes the other half of the polariscope and is placed between the translucent crystal and the eye, some of the rays in each set are made to negative one another and thus to disappear. White light, as we know, is composed of rays of a great variety of colour, and, according to the properties of the crystal under examination, and also according to its thickness, the rays of certain colours destructively interfere with one another and are lost. The light that is left is no longer white, though it was so when it entered the crystal from the polarizer. The coloured residual rays produce a mixed effect, but some tint now predominates. This result is utilized in proving the crystalline nature and characters of minute granules in a powder or a rock.

We have considered this matter at the outset, since many stones that are said in text-books to consist of amorphous particles are now known to consist of crystalline particles, and the amorphous bodies in stones are very few. The finely broken calcareous shells of animals which constitute the great bulk of our limestones are as

crystalline as the calcium carbonate, in the state of the mineral calcite, that cements them together or forms conspicuous veins through the rock-mass.

The essential feature of a mineral is that it can crystallize under favourable conditions; and our brief introduction shows us that we may speak of the constituent particles of almost all rocks as minerals. The constituent particles of the minerals are the chemical atoms that control, by their grouping in the crystalline material, the physical characteristics of the species. Here we have got down to our definitions. We have gained some insight into what a mineral means; and we recognize that stones, the subjects of our later chapters, are masses made of minerals.

CHAPTER III

SAND OF THE SHORE

IT is a misfortune due to our climate in the British Isles that, if we work continuously in the open air, many of our observations must be made when rain is falling or has fallen recently—in fact, we cannot count on dry conditions. The colours of rocks become deepened by the moisture and are thus apt to be obscured; grains of loose materials stick together, united by the film of water that closes in on them like a contracting skin; and, worst of all, our notes cannot be properly written on paper that becomes soaked and softened, or flies away before the wind.

Yet the rain, frequent and persistent, is performing an enormous public work. Penetrating along tiny crevices, it is loosening the cement between mineral particles and setting them free to go wandering on far adventures. It is acting chemically also, dissolving the binding matter in many cases, and slowly attacking the minerals and promoting their decay. As products of this decay, new mineral combinations may arise; but in the great majority of cases these are softer and more friable than those from which they are derived. Some of them, when they are washed out mechanically into the superficial deposits of the district, are again

attacked by the acids in the soil, are worked up into compounds soluble in water, and in due course yield chemical food to growing plants.

The decay of a compound rock goes on in various fashions, and the destruction or even the loosening of one of its mineral constituents leaves the more resisting matter free. The rock-crystals that we found in the veinstone (p. 16) are practically indestructible. They cannot be scratched by a steel knife, while they scratch glass easily, and they break along irregular curving surfaces, since they do not possess the planes of cleavage that allow many minerals to split up into smaller geometrical forms. They consist of crystallized silica, the oxide of silicon, and ordinary acids, even at boiling temperatures, have no effect upon them. In granular forms, they are common and important constituents of granite and other familiar rocks. This mineral is known in all languages and in various spellings by the name of *quartz* (Fig. 1).

Rain-water contains a small amount of carbon dioxide dissolved in it from the atmosphere, which enables it to act as a mild acid in its attack upon the rocks ; but this acid has no power upon quartz. The quartz-grains that are set loose are knocked against one another on the hillside or in the streams, and they thus become gradually reduced in size ; but they are liable to remain sharply edged and angular, and to form the coarsest constituent among the mingled products of decay.

When we sit on the sea-beach (and we will choose a dry day on this occasion) we may well wonder at the quantities of sand. The great bulk of this consists of quartz ; we soon learn to recognize this mineral when we examine its irregular surfaces of fracture with a pocket-

lens, when we note its clearness and transparency, and when we try its hardness by pressing it between two slips of glass. As the waves break upon the shore, they churn up the material of the beach and become muddied by the commotion that they cause. The quartz sinks quickly ; we see its gleaming surfaces as it falls ; but some of the finer grains become washed away seaward, and with them goes all manner of flaky matter, lost to the beach and gained by the great cemetery of the sea.

Tide by tide, day by day, year by year, century by century, the coarser and more resisting material becomes thus sorted out upon the shore. The quartz sand in consequence remains predominant. It is not necessary that the rocks abutting on the coast should supply this mineral to the beach. The waste of the general land-surface, brought down by the rivers from the far interior, provides the great part of the detritus on the shore. The sea redistributes this detritus, always with one result, the accumulation of clean sand, from which the mud and organic impurities have been washed away.

Small shells, brought in by the advancing tides, survive amid the general battering on the shore. They are floated up by the waves, dropped down again into the interstices between the sand-grains and the pebbles, and lie there protected while coarser things receive rude blows. On a sandy shore, the larger shells, the coverings of razor-fish, whelks, and other molluscs, are rarely perfect. The lumps of rock, already rounded by friction against one another in the streams, are spread out as pebble-banks and are used during storms as tools for the undermining of the cliffs. Near the cliffs we find these pebbles ; farther out, the finer material extends, the sand that provides far more pleasant

walking ; farther out again, on the sea-floor itself, are deposits of the very fine quartz sand and the clay from other minerals, which make up the grey and green and black muds that are dredged up even two hundred miles from land.

As the land-edge slowly sinks on the margin of a continent, in response to the mysterious wrinklings that affect the outer layers of the earth, the deposits on the beach can go on growing. The earlier beds of sand are carried seaward, or, rather, the sea is allowed to encroach over them, so that they now lie beneath deeper water than that in which they formed. They are beyond the reach of disturbing waves ; currents may swirl away portions of them, and sweep them up in new banks at other spots ; but in time they are brought into the calm depths where only fine material can be deposited on them from the shore.

Meanwhile, the sands of the shore are thickening, layer after layer ; the cliffs are cut back by the sea that advances over the land ; and a great sheet of sand has accumulated, the older part of it on the seaward edge where it thins out towards deep water, and the younger part of it on the present coastline where it thins out towards the land.

Such a mass is called a sheet or *stratum*, or, if variations occur in the successive deposits, it forms a series of sheets or *strata*. We picture it in our geological diagrams as having parallel surfaces above and below ; but in reality it is lens-shaped, thinning away on all its margins, and reaching its greatest thickness in the region where deposition can be continuously maintained.

The beds that form the mass will not be all of the same character. The rivers from the land-surface may

sometimes be in flood, and will then bring pebbles, rolling over one another, down to the sea ; at other times the sand and mud alone may reach the shore. As the country wastes away, a variety of older rocks comes within reach of the denuding forces, and the material supplied to the streams changes in mineral character and in colour. Hence the deposit in the sea will not remain truly uniform, even throughout a single year. Rapid subsidence or elevation of the sea floor will bring about even greater changes in the texture of the beds that can be laid down. The layer-structure, the *stratification*, of the mass is revealed by the variations in successive beds.

This stratification will be fairly regular in masses laid down at some distance from the shore. Within reach of currents or wave-action, it will be less continuous. A portion of one sand-bank will be swept away, and a new mass will be laid down on the denuded surface, its bedded structure crossing that of the earlier strata, and often indicating deposition on a slope. Irregular bedding of this kind is, indeed, characteristic of material accumulated on a shore.

It may be asked, what has all this to do with stones ? But have we never heard of *sandstones* ? Come into the next sandstone quarry and see what the rock itself will show.

The quarryman calls it a " freestone," if he can trim it well as blocks for building ; or it may be a " flagstone," if it splits easily into flat pieces suitable for paving the side-walks of streets. The place of these flags is being largely taken by artificial stone, that is, by a preparation of fragments of various rocks set in cement. These modern paving-slabs are very lasting and uniform in

quality; but the name flagstone is not likely to be forgotten by those who work the natural stone.

Take up a lump of the sandstone and rub it between the fingers. It crumbles into grains of sand. These can be taken home and compared with the fresh sand gathered on our shores. The grains may be browner on the surface; but boiling in hydrochloric acid will clean them, until they show their clear shining nature. We have first loosened the cement that bound them together into a stone, and now we have dissolved it chemically. If we could do this to the whole rock-mass, we should restore an ancient beach.

The sandstone quarry lies far inland, and we ascend to it, perhaps, five hundred feet above the sea. It is cut in a rock-face, an "edge," as they say in the north of England, which stretches along the hill-front, forming a feature over many miles of country. In fact, the sandstone is sufficiently hard to have controlled the form and the very existence of the hill. The weather has not been able to wear it away so readily as the softer and more clayey rocks below. These form a gentler slope, up which the road winds from the plainland; without the sandstone on the top, these clays would hardly have remained above the general level. The old beach has protected them; the soft and shifting sand, once beaten by the waves, has become the cornice of the country.

There is no mystery about it, beyond the great mystery of the inner happenings of the globe. The stones of the quarry reveal their origin, and we see much more in the cleared face of the rock than we can see while the same type of material is in course of accumulation on a beach. In the first place, the sandstone is clearly stratified. Here are the beds laid down in due succession,

and the little changes of grain, or the little flows of mud between them, allow them to split along their bedding-planes.

Where the flags in a flagstone quarry are very uniform in thickness, something rhythmic was going on when their materials were being deposited. Drier seasons may have occurred periodically, when only little runs of fine mud trickled outwards from the land. A good deal of sand may be deposited off a delta in a single year. We are probably apt to exaggerate the slowness with which strata grow ; floods may bring down immense quantities of rock-detritus, and in a sinking area there is always room for more material. On the other hand, when the sea-floor is stationary, and the deposit is built up to the level of high water, thickening of the mass is naturally at an end, except by accumulation in the river-region of the land.

These considerations, which carry us back to review the conditions of our sandstone edge before it was an edge, may not appeal to Thomas Mason, who now quarries out the flagstones. His name, by-the-by, in this quiet country-side, is Mason, because he is concerned with stones. The edge has been attached, as it were, to his family since the time of Knut the Dane, and you may find his name in Domesday Book, which was written when men still took their titles from their trades. Mason, however, in his own way is a shrewd observer, and he will show us strange bulging ridges on the surface of some flags that he has set aside. These were on the lower sides of the beds as they lay in place, and are moulds of the tracks of large sea-worms or other creeping creatures, which moved over the sand when it was exposed between tide-marks on the shore. The sea went back for some hours, and in

the interval the surface dried. The deposit was just muddy enough to cake and harden, before another wash of sediment came across it from the land. This new bed filled up the hollow tracks and preserved them for all time in the growing rock.

As the sea-water sways forward and backward—for there is a forward and a backward movement as each wave breaks, in the general advance or retreat that we call flow and ebb—the sand, on quiet days, is ridged up into sinuous ripples, and even these may be preserved as "ripple marks" in stone. Sometimes rain falls while the long flat of the estuary lies exposed, making little pits upon the surface; sometimes a land-animal moves across, leaving characteristic footprints (Fig. 17). These marks may also, under favourable conditions, be recorded in the flaggy sandstones; but they are far more likely to be preserved in the deposits of lakes than in those of ordinary seas.

Lakes may lose water by evaporation, or by some defect of the rainfall that supplies the entering streams. The shores may be low, and the land-surface is continued very gently under the water of the lake. A slight shrinkage of the body of water leaves many square miles of delta-deposits exposed, and months may elapse before they are again covered by the lake. Hence they have a good chance of becoming caked and firm and dry. In shrinking, they break open if they contain much clay, giving rise to what are known as sun-cracks. The next deposit, which may consist of wind-borne sand, fills up these cracks, just as it fills up the rainprints and the footprints. From the same causes, operating millions of years ago, impure sandstone strata retain structures that tell us something of the climatic conditions under which

they came into existence; and now and then they assure us that whole families of bipedal reptiles walked across in the sunlight and enjoyed an outing on the shore.

Many of the strata on the sandstone edge are not so uniform and flaggy. Here and there in the quarries the bedding is irregular and confused. This *current-bedding* is a record of the variable wash of waters on the area of the beach. The best stones for building come from places where deposition of grains of similar size went on quietly for a considerable time. The blocks can here be trimmed evenly in almost any direction; but they are quarried along their natural surfaces of jointing and along their planes of stratification.

The joints must not be regarded, like those of rocks that were once molten, as due to shrinkage by loss of heat and water. They often pass right through the larger pebbles in the rock, and they evidently result from torsion of the mass. The strata are warped and twisted by the forces that crumple up, along certain lines, huge complex mountain-chains, and they crack along two main directions, approximately at right angles to one another. Thomas Mason knows the trend of these "master-joints" full well, and his quarry-face is worked back parallel with one series of them.

And here surely, lying apart in a stone that would be rejected by the builder, is the impression of a fossil shell. The calcium carbonate that formed the shell itself has disappeared; but the fine sand filled it up as it lay upon the beach, and we now have a mould of the interior. These curving hollows in other parts of the stone show where similar shells remained long enough for the growing rock to consolidate round them (Fig. 2). The water

Fig. 2. Marine Sandstone with casts of Shells. Cretaceous age, Saxony.

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oozing through the mass dissolved the actual shells in course of time ; but plaster or sealing-wax may be run into the hollow and will restore the form for us by filling the gap between the internal and the external mould. In this way many exquisite fossil forms have been recovered, and they may then be compared with the specimens well preserved in stiff impermeable clays.

Such fossils will help us to decide if a given sandstone was laid down in a sea or in a lake. The cementing material may be much the same in either case ; but a red ferruginous cement turns our thoughts at first to lake-conditions. A number of bacteria in freshwater swamps influence the extraction of iron oxide from the salts of iron that are soluble in the water, and precipitate it round themselves and round the mineral grains that accumulate to form a future rock. But the inorganic oxidation of salts of iron brought in by the waters that percolate through any sandstone may throw down a similar cement in the course of ages, and the colour cannot be relied on as an indication of an ancient lake. Some of our British sandstones, moreover, have been stained by water soaking in from redder beds above.

Lakes as they dry up, and seas in which too much calcium carbonate is supplied by springs or rivers, may deposit calcium carbonate as a crystalline cement between the sand-grains. This cement effervesces when acid is put upon the rock, and it tends to be etched out by rain-water if the stone is used for building. As a contrasted example, silica may be imported into a sandstone by waters that have gathered it during their wanderings in the earth's crust. This oxide, which has,

as we see, the same composition as the quartz-grains, is deposited round them in a crystalline state, that is, as quartz. Each grain thus becomes coated with fresh silica; it grows larger, and Nature attempts to reconstruct the original crystal from which it was worn down long ago.

More than this, the grain may originally have come from some mass, such as granite, in which it never had a chance of assuming a proper crystalline form. The new deposit tries to atone for this, and adds, where space in the rock allows, crystal-faces to the angular or rounded grain. These faces are hampered in their development by coming against those of a neighbouring grain, and ultimately the deposits interlock, the mass being then cemented firmly. But now and then this tendency to form crystals remains clearly seen; the grains become surrounded by facetted quartz, as in a well-known red sandstone from Penrith in Cumberland.

The ultimate result of the cementing of a sandstone by silica, which separates out from solution in the form of quartz, is the very hard intractable rock called *quartzite.* Its granular structure is almost hidden, and is best revealed by the presence of little specks of some other mineral beside the quartz. The cement and the sand-grains are of equal hardness, and the interlocked structure allows the surfaces of fracture to pass through rather than round the grains. Torsion in the earth, acting on the brittle mass, produces a number of small joints, and the rock breaks up on exposure into little sharply-bounded blocks, like those produced by the hammer of a skilful road-mender. These fall down in all directions from a hill-top as it wears away, and quartzite mountains thus tend to have a conical form.

Soil does not gather on this insoluble and intractable material. Despite the rainfall of our temperate zone, quartzite develops rock-deserts within the British Isles. The bare grey surfaces of the Twelve Bens of Connemara, and the crests of the Torridonian hills of north-west Sutherland and Ross, are examples of how mountain-scenery may depend on the qualities of a stone.

We have treated our Edge, which is part of a band of sandstone stretching far across the country, as an ancient beach, lifted high and dry and weathered out as an escarpment. The quarry-face, which first attracted our attention, shows sufficiently the stratified structure. In many districts, however, the coarse pebble-beds of former shores remain, and among these we can picture still more readily the beating of the waves where now the forest climbs. The pebbles indicate the kinds of rock that lay in those ancient times up-country ; but we must remember that the resisting stones are preserved in far greater proportion than the friable and soft ones, and that pebbles from quartzite or from quartz-veins will largely predominate where the land has long been swept by rivers and where the detritus thus carried down has been subject to the battery of the sea.

These pebble-beds of former days give us the rocks known as *conglomerates* (Fig. 4). Scarcely any fossils can be preserved under the conditions that prevailed in the formation of these tumbled masses, and we have to search the associated clays or sands, products of more quiet waters, to prove whether a conglomerate has been formed in a sea or in a lake, or perhaps in an extensive river-flood. Many of our coarse conglomerates have originated in the periodic rush of torrent-waters over the

land, and to understand them properly we may have to look outside the limits of our islands. Some of the finest conglomerates are of Devonian age. Let us seek at once the Old Red Sandstone.

CHAPTER IV

OLD RED SANDSTONE

THE Scottish stonemason, Hugh Miller (1802–1856), who became a well known author and geologist, long ago made the system of rocks that underlies the coal-bearing beds of Scotland famous as the "Old Red Sandstone." A sandstone series of later date follows in Britain on the coal-bearing strata, and this "New Red Sandstone" is now divided between the Permian and Triassic systems. The Old Red Sandstone is recognized as a freshwater and terrestrial representative of marine beds that are styled Devonian in the south of England and in the region of the central Rhine; but the name adopted by Hugh Miller, taken from the typical rock, clings by a just tradition to corresponding deposits throughout the world.

The Old Red Sandstone is not all red; but its general red or purple tint is one of its most interesting features. The pebbles in the conglomeratic beds (Fig. 4) are reddened on their surfaces; the cement, even when siliceous, as in the quartzites (p. 32), is red and suggestive of iron rust. The prevalent rock-fragments are hard and quartzose; Old Red Sandstone conglomerates form in consequence resisting masses on the surface, with little serviceable soil.

We know them in the bare and purple hillsides that bound Loch Ness near Castle Urquhart; in many of the higher levels of the Cheviots; and in the mountainous land from Waterford to Cahersiveen, where at one end the cliffs of the Comeragh Mountains rise 1,100 feet sheer from little lakes, and at the other the serrated crest of Carrauntoohil looks down on the wilderness of Glencar.

The fossil fish dug out and studied by Hugh Miller and his successors of the Edinburgh geological school show that much of the stratified Old Red Sandstone accumulated under water. But part of the coarser and conglomeratic material, as later workers have realized, gathered on the surface of the land.

As exploration of the earth has gone on, and as the routes of travellers have been guided less by the needs of trade-development and more and more by the ambition of pure discovery, our knowledge of deserts has increased, and desert-lands have proved attractive. There are cold deserts and hot deserts, their common character being lack of rain. The arctic ice-field, floating on the arctic ocean, is a desert. Islands environed by it are devoid of vegetation, since any water that falls on them is in the solid crystalline state and remains unmelted throughout the year. There are deserts in central Asia and in northern Africa, because the geographical conditions prevent sufficient moisture from reaching them by streams or in the air. The existence of deserts in such regions is not a mere question of high temperature, since rain falls copiously in hotter regions much nearer to the equator.

In some cases, an area remains dry for a large portion of the year, and is subject for a few months only to

violent downpourings of rain. The statement of the total annual rainfall in such localities may look inviting to the settler; but the water thus supplied is badly distributed for his needs. It may fall only in summer, too late to encourage the growth of crops; or it may fall, partly as snow, in a cold winter season, and disappear mainly by evaporation and by running off the surface. In either case, desert characters are perpetuated simply through a lack of well distributed rain.

A period of clear skies and strong sunlight—not the low sunlight of the polar regions, however continuous that may be—gives rise to an intense drying of the surface of the earth. Such water as can rise through the delicate conducting passages in the soil is lost by evaporation, and deposits the salts that it held in solution as a cement between the soil-grains. Crusts and "pans" of mineral matter develop to such an extent as to obscure the original structure of the surface-rocks. Salts of iron, in particular, derived from the decay of various common minerals, accumulate to form a hard insoluble cement. Various genera of bacteria aid this process in all climates, the final product being brown iron hydroxide, that is, common iron rust.

In extreme cases of tropical heating, where the temperature of the surface-soil may rise in daytime as high as 120° F. (50° C.), the iron rust loses its combined water and passes into the "anhydrous" mineral haematite, red iron oxide, which is still harder and more resisting, and still further affects the general colour of joints and the exposed surfaces of rocks. The solid rocks themselves break up under the influence of strong heating by day and rapid chilling by night, as the heat radiates into the cloudless air. Alternate expansion and con-

traction send showers of blocks down the hillsides, and these grow into great taluses, banked at their upper ends against the slopes and spreading out in fan-like forms towards the lower ground. When the country is not absolutely arid and when the rains are seasonal, the sudden attack by water sweeps much of this loose material away and spreads it out broadly over the plains. The caked and hardened ground will not receive the water ; a large part of the surface, in fact, is mere bare rock, cumbered, perhaps, by angular blocks, from which the winds have blown the occasional fine dust away. The crumbled powder that might have formed a soil is thus dispersed almost as it grows ; even if it hides in crevices or accumulates for a time as a superficial sand, it is washed out of the country by the rush of water that rises a foot or more in flood.

The ravines, which are mere dusty grooves in the months of drought (Fig. 3), are now rapidly filled by flowing streams. Their deltas may spread out into some lake, which manages to maintain itself throughout the year, or across areas that are commonly mere wastes of pebbly stones. On their farther edge the deposits die away where the floods sink into the absorbing sands. "Flood-denudation," as it is called, may thus produce widely-spread sheets of pebbles, which become irregularly stratified as they increase from year to year.

In the first chapter we promised ourselves excursions beyond the homelands. Come a little way westward from the harbour of Algiers, by the road that leads so temptingly along the promontory to the blue water at Pointe Pescade and Cap Caxine. The streaky grey granitic rock appears in places, sending out spurs into

the sea; but its over-burden, on which the forest of Aleppo pine and cork-oak climbs, is a strong red-brown loam, full of angular fragments that have slipped down from the steeply rising hills. The contrast is extremely striking, between the pale crystalline rocks of the headlands and the thick overlying accumulation of the reddened products of their decay. Though the rainfall is high along this coast, there are seasonal intervals of hot clear sunshine. Denudation, by which we mean the destruction of the land-surface, occurs here under alternations of parchingly dry and torrentially wet conditions. The streams have cut little ravines down to the sea, and in these the fragments from the foothills of the Atlas Mountains are worn into pebbles before they reach the shore. Here we have a picture in little of the formation of the Old Red Sandstone, and the picture is still being designed and coloured before our eyes.

When we cross the high steppe-land between the two Atlas ranges, and descend towards the dry basin of the Sahara, we traverse areas of increasing aridity. The ground is loosened, as it were, by sunshine, and the banks of the stream-cuts are made ready for the floods. When these arrive, the surface over wide areas is in a state of flux. It reminds one of a tundra in far northern lands when the ice-bound soil begins to thaw. The sides of the shallow ravines collapse and mud-flows spread across the customary tracks. I have seen the railway that struggles inland among the camel-routes to Kaiouan in the Tunisian steppe endangered and swamped in this way after a night of heavy rain. In the same month the road to Biskra was carried away, and detritus was added to the pebble-fans that stretch towards the edge of the Sahara.

This road, from Batna to Biskra through the Aurès chain in eastern Algeria, is far more interesting than the railway, and is stable enough down to El Kantara in all seasons of the year. After leaving the river-systems that run so naturally down the northward slope of the country, and carve out superb gorges on the steep Mediterranean coast, it is a novelty to find another system of streamlets running southward, not to a base-level at the sea, but away into the heart of Africa.

Though it may be only October, with the temperature of a warm summer-day in England, the nomads with their camels, their baby-camels, their wives and children, and all their worldly goods, already find it chilly and are taking the highway to the south. Below Aïn-touta the road drops in bold curves to a veritable rock-desert (Fig. 3). The stratification on the crags to westward stands out clearly, as it does in the arid lands of Arizona or the Cape Province. The débris weathered from the heights rests awhile upon the gentler shelves, but ultimately slips down to join the brown fans that spread outward from the hills. Some of it lies in angular blocks, among which the roadway winds ; some of it topples over into the uncertain groove of the Oued Tilatou, and in time becomes worn into a pebbly sand. The barren wall of the Saharan Atlas, brown on all its ledges and turning to gold where touched by the unclouded sun, seems to cut off the still more desert land before us ; but it is cleft, as it were, by the narrow gorge of El Kantara, where the Arab invaders wondered at the bridge planted by a Roman legion, and gave its name to a passage now famous through the world.

Below the gorge, just where the stream supplies water by soaking sideways into the level land on either

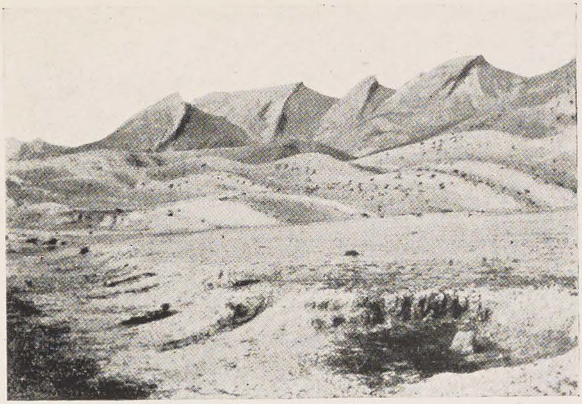

Fig. 3. Rock Desert. El Kantara, Algeria.

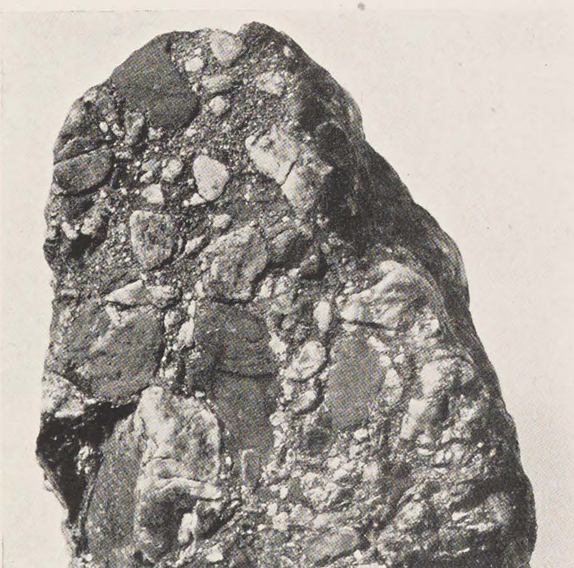

Fig. 4. Old Red Sandstone Conglomerate. Ireland.

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bank, the ground is no longer desert, and an oasis rich with palm-trees attests the fertility of the soil. So, in Old Red Sandstone times, the quaint old-world forests, the first that the earth had known, spread where water was persistent, perhaps close against semi-arid tracts. The plants associated with the Old Red Sandstone are known as fossils in many lands of the northern hemisphere, and their occurrence, though their remains are preserved in lake-deposits, gives further evidence of the continental nature of the rocks.

Out beyond the narrow passage of El Kantara, the open country slopes to the Sahara edge. The wind here has free play upon the flood-detritus; the banks of stones are swept by blasts of sand. A stone in an ordinary stream receives a characteristic form; it becomes rounded by friction with its neighbours, but is not reduced to a perfect sphere. A water-worn pebble has usually two flattish surfaces, and comes to rest on one or other of them. When the force of the water slackens, so that a stone of this particular size can no longer be pushed forward, smaller material still flows past and over it, wearing a second flat surface parallel with that on which it rests. When the flood increases and the pebble is again moved forward, it is slipped over its neighbours rather than rolled over on them; it preserves its general form until it reaches its true battle-front and comes under the relentless pounding of sea-waves.

On land, under the influence of sand blown past it, the stone is similarly reduced in size. The cutting action of the sand is, indeed, more effective under air-flow than in the stream, since the grains are not so efficiently buoyed up and floated apart from one another. The

stone itself is hardly shifted, and cannot escape from the sweep of sand-grains over it. It rests on one of its flat surfaces while the other is continuously exposed. The drift of the sand-blast is likely to continue long in the same direction, according to the prevailing winds or to the eddy from a neighbouring wall of rock. Hence the stone is carved away into an elongated form ; its sides slope up to a ridge upon the top, and its cross-section becomes triangular.

Such stones, sub-aerial pebbles, are known by the German name of *Dreikanter,* and their occurrence in rock-masses of ancient date are excellent evidence of desert-origins. The etching of the exposed surfaces is, moreover, characteristic. Little wandering grooves, uniting with one another, are cut out, as if an artificer had tried some form of patterning. The upstanding and the excavated portions alike receive a polish, quite unlike the duller and smoother surface, with tiny cuts in it and signs of hammering blows, that we find in pebbles from a stream.

Dreikanter have not yet been found in the Old Red Sandstone, though they occur " fossil " in other European deposits. Sands of arid regions are liable to consist of highly rounded grains, owing to the frequent collisions experienced when travelling through the air. Attention has been well called to this point in connexion with the red sandstones of Triassic age in England. At Charnwood Forest, W. W. Watts has shown that the granite, which was probably intruded in the Devonian period, has been worn by the sand-blasts of Triassic times, and he has reconstructed for us a rock-landscape of the desert epoch. Wind-borne sand-grains have been recognized in the Upper Old Red Sandstone of

northern Scotland ; but at no time were the conditions of its deposition so typically arid as those of the Trias or " New Red Sandstone " (p, 191). In both systems of rocks, the prevalent red colour is suggestive, and supports the other evidence, inviting a comparison with the deposits that are accumulated on semi-arid land-surfaces at the present day.

Many interesting comparisons may similarly be made between modern lake-deposits and the fish-bearing strata of the Old Red Sandstone. The sudden choking of fish by runs of mud in modern rivers has been cited to account for the local abundance of certain species in a fossil state. The marine Devonian beds of Devonshire, including a handsome limestone with corals and sea-lilies at Plymouth, show us where the margin of the northern continent crossed the British region. From this we may trace the coast-line eastward into Europe and westward to the United States, and thus gain a certain insight into the geography of far distant times.

Blocks of conglomerate in a museum are thus suggestive symbols ; they carry our thoughts across the changeful earth. Running water rounded their pebbles, the hills sent down their sand. The history of the common stone is a part of the history of the globe, and the cold dead rock provides a link in the chain that unites all living things.

CHAPTER V

A SLAB OF GRANITE

ONE of the most handsome stones, and one with a great range of colour and structure, is *granite*. In the later nineteenth century, when wealthy corporations revived in their offices the splendours of imperial Rome, polished granite from many lands became familiar in slabs and columns. The name, indeed, is rather loosely used in the stone-trade, to cover a variety of crystalline rocks. Geologists restrict it to those with some 72 per cent. of silica, the surplus of which crystallizes out as quartz ; this mineral is associated in granite, as almost every schoolboy knows, with others called alkali-feldspar and mica. The mica may be colourless, bronzy, or almost black.

A walk along the streets of a prosperous modern town enables us to study granite to advantage. It is as a whole hard and takes an excellent polish, though the mica makes soft dull spots among the other minerals. Its mineral constitution enables it to resist the acid atmosphere of smoky cities. Where marble loses its polish promptly and becomes a prey to every rain, polished granite remains smooth and lustrous. Who builds in granite builds very much for future ages.

The coarser and the common grey kinds can be sawn

and trimmed, and used for the ashlar-work of massive walls. The coloured varieties, and those with special attractions of structure, may have a high value when smoothly ground and polished.

The rock of Peterhead near Aberdeen has long been a favourite for its red colour and its uniformity of grain. That from Shap Fell in the high moors of Westmoreland, where the coach-road from London to Edinburgh climbs to a height of 1,300 feet, is sometimes grey, sometimes red, and is in either case set with large red crystals of felspar that give it an effect both startling and bizarre. This Shap granite provides a good and attractive introduction to other types that are not so self-assertive.

A polished surface helps its study very greatly. Before H. C. Sorby introduced the general use of thin sections of rocks, Achille Delesse in France had shown how much can be done by directing a lens or a microscope on a smoothly polished rock. The light is not scattered by a multitude of reflections; minerals that are translucent allow it to penetrate, and the eye can look down into their interiors. The contrast between one mineral and another is made manifest, and the general structure of the rock at once appeals. I have on my table as I write a letter-weight cut from the Shap granite; this will serve very well as a sample of the stone.

The groundwork is granular, but there is no obvious cement. The constituents fit into one another and round one another, as if born much at the same time. There are white granules and pink granules, which have occasionally somewhat rectangular shapes, like little bricks. Between them are clear and glassy-looking grains, and

black things which refuse to take a polish, and which are individually smaller than the rest. These dark constituents are evidently soft ; if we tilt the surface and secure a broad reflection from it, they are seen to lie below the general level ; they have been partly torn away in grinding.

Another feature that comes out is the grouping of the dark mineral round the more granular and larger ones. The dark material seems to have been deposited round the other crystals, or to have been pushed aside during their growth. The latter suggestion appears most probable, since some of the dark matter is caught up in the granules—not very often, but sufficiently often to show that it developed a little earlier in the mass.

We leave aside for the present the handsome pink-red bodies that float as giants in the general fine-grained ground ; the dark mineral surrounds them also, not continuously, but in a zone of specks, a few of which have become included in these larger crystals.

The fact that there is a tendency in the duller brick-like granules, despite their crowding together, to assume regularity of form reminds us of the crystals that we have already realized in rocks. As a matter of fact, granite proves to be crystalline throughout ; its ground is a closely associated mass of crystals. This was discovered first in coarse varieties, where the constituents could be picked out from one another. The various kinds of substances were compared with choice mineral specimens developed under happier conditions. The gleaming six-sided plates, the mica that we studied in our first chapter, were found to be a very frequent constituent, and they have evidently secured their shapes by developing before the other minerals. The brick-like bodies were soon

recognized as *feldspars* (p. 52), or, as we unfortunately write in England, *felspars*, and the translucent granules, which in the rock granite never get a chance of showing off their proper crystal-form, proved to be *quartz*, rock-crystal. This mineral gives special hardness to the rock.

These mineral substances, when submitted to the chemist, are found to have definite constitutions, or constitutions in which one element perhaps varies somewhat in amount in specimens from different rocks or different parts of the same rock, being replaced by an analogous constituent without any great change in the characters of the crystal. The feldspars of granite thus have some range of composition, the predominant one, called orthoclase, consisting of silica, alumina, and potash (potassium oxide), with some soda (sodium oxide), the sodium evidently varying against the potassium. Other feldspars may be present in smaller quantities, such as those in which sodium prevails over potassium, or, as very commonly occurs, feldspars in which sodium and calcium oust the potassium almost entirely.

It has become necessary to make several species out of the feldspar series, since the range of chemical composition carries with it a range of physical and crystallographic characters. The specific gravities of these species rather naturally differ, and the angles between the crystal-faces respond to the differences in the chemical atoms in the mass. The feldspars, however, as a series may be stated to be aluminium silicates, with potassium, sodium, calcium, or all of these. In granite, as we said at the outset, potassium-sodium felspar prevails.

Here we are met by one of those difficulties of Nature, which show us that chemical composition is not abso-

lutely a fundamental character in mineral species. We shall see (p. 81) that calcium carbonate under different conditions gives us on the one hand calcite and on the other aragonite, minerals of distinct form and differing in their physical properties. Similarly, a compound of silicon, aluminium, potassium, and oxygen, with or without some sodium, gives us in granite a characteristic feldspar, *orthoclase*, a feldspar named from its having two directions of cleavage well developed at right angles to one another. Yet very commonly, and far more commonly than was formerly supposed, the same constituents in the same relative quantities crystallize in a form very near that of orthoclase, in which, however, the two cleavages, and the external planes that are parallel with them, differ by half a degree from a right angle with one another. This difference is quite enough to put the crystals in another class ; we have to establish a distinct species, which receives the name, from its " little slope," of *microcline.*

Both orthoclase and microcline are potassium-feldspars. By custom, the constituents are calculated as their oxides ; the potash may amount, when no soda is present, to 16·89 per cent. Commonly, however, there is a certain amount of soda, up to about 5 per cent., in orthoclase. When about 6 per cent. of soda is present the two cleavages are no longer at right angles and the feldspar, according to J. P. Iddings, is always microcline. Yet, on the other hand, microclines occur with a small or practically no percentage of soda. It is safest, until we can apply microscopic tests, to speak of the common feldspar of granite as potassium-feldspar.

It is interesting to be able to prove the presence of the potassium in orthoclase or microcline without the task of

making an elaborate wet analysis. More than forty years ago, J. Szabó, of Budapest, showed how feldspars could be discriminated by the colour, and the intensity of the colour, imparted by small fragments of the same size to the invisible flame of a bunsen gas-burner. Szabó's methods have been modified in some cases, and here is an easy way by which the richness of a feldspar in potassium may be ascertained. A loop is made at the end of a platinum wire—in happier days this used to cost a penny an inch ; this is moistened, and sodium carbonate is picked up on it and fused, until enough is obtained to form a bead about 2·5 mm. in diameter. This bead colours the flame a strong yellow ; but a sufficient thickness of blue glass cuts this colour off, only a narrow blue column being seen if the flame is very luminous. The blue glass commercially obtainable allows a pinkish tint to come through from any ordinary luminous flame, and a thickness of at least 5 mm. is required to abolish this effect. Squares of blue glass are cut and laid one over another. When it is certain that no light that can be mistaken for a potassium reaction will be received from the sodium carbonate bead, all is ready for the test.

The bead is moistened, and a fragment of the feldspar about 2 cubic mm. in bulk—say, $2 \times 1 \times 1$ mm.—is picked up on it and carefully inserted in the edge of the bunsen flame and 5 mm. above the top of the burner. The sodium carbonate is an excellent flux for silicates ; the particle is soon absorbed and disappears ; it is well to allow two minutes for this process. Now examine the flame through 5 mm. thickness of blue glass ; even small quantities of potassium will reveal themselves by giving a perceptible pink-violet flame ; but soda-

orthoclase and orthoclase impart this colour to a large body of the flame, and orthoclase gives an intense pink-violet column above the bead itself. The same reactions of course occur with microcline and soda-microcline. The sodium in a feldspar obviously cannot be estimated in this way ; but sodium-calcium feldspars give a yellow coloration in various characteristic degrees when particles of equal size are fused by themselves in the bunsen flame.

Since the prevalence of potassium in the feldspar is a mark of the rock-species granite, such a test may be often useful. For geologists, the rock is called a *quartz-diorite* when other kinds of feldspar predominate, and in such granitoid rocks there is usually less silica as a whole, while a greater amount of dark minerals, which are the soft minerals in this case, appear throughout the groundwork. Though the trade uses the name granite for a great variety of stones, there is a real advantage in accepting the restrictions made by the geologist. A well chosen granite is on the whole a better stone than a quartz-diorite.

Coming now to the dark material, we may at once say that it is a *mica*. The species is dark-coloured in our rock from Shap ; but in granites from Cornwall, from Dublin, and many other places, the mica is colourless and quite transparent in thin flakes. Light and dark micas often occur in the same rock. Their most striking common character is their cleavage ; no other mineral surpasses them in this. A knife-blade enables us to split off flakes far thinner than a sheet of foreign notepaper ((p. 15)). The crystals rarely become elongated in a direction perpendicular to this cleavage ; they remain usually as six-sided plates. All micas are

easily scratched by a knife ; in this they differ markedly from unaltered feldspars, and this accounts for the depressions that they cause in the polished surface of the granite stone. A coarse-grained granite is useless for ornamental work.

Chemically, the common micas are aluminium potassium silicates, with less silica than the feldspars, some hydrogen, and in the dark varieties a good addition of iron and magnesium.

The quartz in granite usually fits in between the other constituents. It represents the silica that was not wanted in building up these minerals. So much silica was present that even the 65 per cent. required by potassium feldspars did not utilize it all. Its granules are an essential feature of the rock, not to be scratched by a knife, not decomposed by common acids, and remaining behind as persistent sand-grains when a granite mass breaks down through long weathering and crumbles on the moor.

Some granites contain another dark mineral in place of mica ; at times this is *hornblende*, a silicate that crystallizes in prisms, is distinctly harder, and takes a reasonable polish ; at times, as is often seen in Cornwall, *tourmaline* occurs, in its black variety, called by miners "schorl." Tourmaline represents an attack on the rock by acid vapours underground. The micas and feldspars are often removed, and hard lustrous schorl spreads through the rock in delicate needles, associated with a secondary growth of quartz. Here and there a fine three-sided prism is prominent in the reconstructed mass.

The large pink-red crystals in the granite of Shap give it what is called a *porphyritic* character. The purplish rock known to the ancients as porphyry is speckled in

the same way, and hence the term. In our granite the large crystals are potassium feldspars, which have succeeded very fairly in producing their proper crystal forms. At Karlovy Vary (Karlsbad) in Bohemia conspicuous crystals of orthoclase occur in the granite quite as well developed and well bounded as if they had grown under favoured conditions in a laboratory. They become detached from the rock and lie about in the soil, whence the name *feldspath* or "field-crystal." We shall return to such porphyritic crystals later.

A very interesting feature of granite, and one annoying to the decorative architect, is the frequent occurrence of dark patches, sometimes irregular, sometimes with a rounded outline, which break the continuity of the rock. They were studied by J. A. Phillips and other geologists in the polished surfaces of London buildings; but true conclusions in regard to their nature cannot be arrived at until we walk across great natural surfaces in the field.

It may now be just as well to take the train to Shap, a few miles to the north of the pass over the barren fells. The quarries, developed with such vigour for the markets of our imperial towns, provide us with splendid cliff sections and material for a generous study of the rock. There is, moreover, an excellent little hotel, well known to geologists before the motorist "discovered" the beauties of our country. The classic work on the Shap granite is a paper by A. Harker and J. E. Marr (*Quart. Journ. Geol. Soc., London*, vol. 47, p. 266, 1891), which gives references to earlier publications. Students of rocks will not omit to make their notes from this, and we may well quote here the analysis made for the authors by J. B. Cohen:

	Granite Shap Fell, Westmoreland.
Silica	68·55
Alumina	16·21
Ferric oxide	2·26
Manganous oxide	0·45
Magnesia	1·04
Lime	2·40
Soda	4·08
Potash	4·14
	99·13

Sir Jethro Teall (*British Petrography*, plate 35, 1888) describes the mineral constitution of the rock, and gives a beautiful picture of its appearance in thin section under the microscope.

In the field, no sign of bedding occurs throughout the crystalline mass, but the granite is seen to be well jointed ; it has given way before the earth-stresses, or, let us say at once, before it finally settled down. A rock of this kind, with no sign of fragmental structure, and crystalline throughout, resembles a mixed precipitate—the constituents seem to have been in solution and to have separated out as the solvent drained away. Yet there is another possibility, well known to workers in glass and metals. The whole mass may have been molten, and crystallization took place as the constituents reached their successive "freezing-points." We know from the springs of Wyoming and Algeria (p. 94.), to say nothing of Bath in our own country, that the interior of the earth may be locally very hot. We know from the occurrence of volcanoes that it may be hot enough to melt silicate rocks. The Shap granite, a mass with a rounded border-line cutting the adjacent rocks,

and exposed as a boss $1\frac{3}{4}$ miles long by $1\frac{1}{4}$ miles across, may be the top of a dome that reaches far down into the earth. In the huge masses of granite in the Alps, uplifted 15,000 feet above the sea and dissected by valleys reaching down 10,000 feet, we gain some impression of the size of the cauldrons in the crust. The study of volcanoes shows that steam is one of the most conspicuous features in the eruption of molten silicate rocks. Water and many substances that come out in a gaseous form are evidently mingled with the " melt " in the earth's interior. Granite may have been melted in the company of acid waters under pressure. The phenomena known in dry melting may thus have been combined with those of solution at high temperature. In due time cooling set in ; but the loss of liquid was a factor in promoting consolidation.

These conclusions were not easily arrived at. They have resulted from prolonged study of the characters and relations of granite in the field. Using the old term *igneous* for rocks that have at some time been naturally molten, we say that granite is an igneous rock.

One curious and suggestive feature is seen in the Shap quarries. A joint-face may now and then be marked by a layer of red feldspar, which has grown along it almost to the exclusion of other constituents. This suggests that final crystallization, the crystallization of the ground, took place after the mass had reached a very stiff and viscid state. Already, in the stage when the large feldspars were developing, it was sticky enough to crack as vapours escaped from it, as it diminished in bulk, and as it settled in the cauldron under a roof of other rocks. Along these cracks large red feldspars formed.

The groundwork ultimately developed a close-set crowd of crystals ; but a long time may have elapsed during which consolidation was still going on. Massive lava-flows that are erupted at the earth's surface may remain hot enough to ignite sticks for many years. There is plenty of evidence in the case of granite that the cooling took place underground—the completely crystalline character, combined with a coarseness of grain, is one of many arguments that may be adduced. The freezing out of a particular constituent would go on rapidly when the right conditions were attained ; but it might be centuries before the right conditions favoured the crystallization of all the material of the mass.

Hence we may think of the crystals that give the rock its porphyritic character as developed at an early stage. In many rocks such crystals have been attacked by matter round them after they developed ; their outlines are corroded, their surfaces are dissolved away ; they are penetrated by insidious tongues of matter from the ground. In this they resemble the larger crystals in lavas ; in both cases conditions have changed during the prolonged history of the molten state. A reheating may have taken place ; or earth-pressures that favoured a particular type of crystallization may have been partially removed. Slowness of cooling and long maintenance at the correct temperature are the great factors in producing crystals of unusual size. A granite in which all the constituents are coarse has consolidated in the lower regions of the crust.

Another feature that we appreciate promptly in the quarry-walls and quarry-heaps of Shap is the abundance of dark inclusions (p. 52). These are well discussed by J. A. Phillips (*Quart. Journ. Geol. Soc. London*, vol. 36, p.1,

1880, and vol. 38, p. 216, 1882). While most authors call these objects " inclusions," very many have adopted difficult ways of accounting for them. Even the angular ones, which so closely resemble fragments carried off from other rocks, are often held to be concretions separated out from the molten mass during consolidation.

The dark patches at Shap are so often rounded that I am not going to quarrel with any one who speaks of them as concretions (p. 103). They often are chemically allied to the granite, and they contain again and again handsome crystals of red potassium feldspar. But the granite along its margins has penetrated a group of dark lavas belonging to the Ordovician system of rocks. The alteration of these has been carefully studied by Harker and Marr, who would probably not agree with all that is here set down.

I have little doubt that the " inclusions " at Shap, the inclusions that may be noticed in our London columns and façades, are genuinely inclusions, and represent for the most part fragments of the older lavas, carried off as the molten granite rose, or as these older lava-layers sank into depths where they could be attacked by molten rock. The inclusions contain, it is true, minerals from the granite, and even entomb the fine red feldspars. J. A. Phillips found one of these large crystals partly within and partly without the margin of an inclusion. Though changes are rapid in London buildings, this example may probably still be seen in Nicholas Lane, E.C. 4. Phillips used it as an argument to show that the " inclusion " had separated out from the molten granite. But it may now be used in quite another way.

A great squirt of granite, a *dyke*, filling a fissure in rocks on the coast of the county of Down, has passed

through an older squirt of dark lava (basalt), which it fairly easily melted up. The lumps of basalt that were picked off, and were not entirely absorbed, revenged themselves on the invader. They formed molten pools in the granite and drew granitic material into their interior, including crystals of quartz and red feldspar that had already developed when the granite rose. The resulting mingled masses are rounded and look exactly like concretions ; but there can be no doubt as to their history when they are studied in the field. A. Harker has corroborated the reasoning in this case by discoveries of similar rocks in Skye. The large feldspars and the quartz grains, which are now surrounded by an envelope of minerals deposited from the remelted basalt, are thus known to be foreigners brought into the dark inclusions.

The angular and the flaky forms of inclusions in granites other than that at Shap can be easily and surely connected with their mode of origin. Some consist entirely of dark mica ; in others aluminium silicate has developed in the form of the mineral andalusite ; in some highly altered cases, alumina has been absorbed in such excess into the granite as to give rise to notable crystals of grey or red-brown corundum, which we might call sapphires or rubies on a large scale, if only they were clear. We must study these occurrences on the walls of Nature's laboratory.

The fragments included in the igneous invader are in all stages of alteration, penetration, and absorption ; but they were in the first instance fragments from the wall. The main mass of granitic matter in the earth-cauldron is so large, and there is so much possibility of drainage of foreign matter down into the depths, that the chemical and mineral composition of the whole may not be very

markedly affected. But here and there along the junction, that is, along the margin of the cauldron, the process by which the inclusions become diffused is vividly and unmistakably declared. Microscopic analysis may be absolutely necessary if we are to appreciate the later stages ; but by itself it is a very partial guide as to what may or may not have happened in the earth. In Chapter VI, we will begin on the edge of the cauldron and move inwards ; long epochs of denudation have made observation easy for us in the open country.

The most remarkable cases of absorption and mutual interaction are provided by the rare "spheroidal granites," in which ovoid bodies 15 or 20 cm. long lie as crystalline concretions in a ground of ordinary type. The best known example of this structure, which has been styled "orbicular," is an ornamental stone from igneous dykes and boulders in Corsica. This rock is granitic in structure, but has too little silica and too much magnesia and iron oxide for a granite. It is an exceptional member of the *diorite* group. The beautiful spheroids in it are well revealed on polishing. They consist of layers of hornblende and calcium feldspar, the dark green and the white minerals presenting a fine contrast. A radial structure, as in many concretions, is clearly shown in the mineral layers. The unusual nature of the rock led to its use for snuff-boxes, and a variety of ornamental objects, which were made in memory of the Corsican emperor of the French.

I cannot answer for the origin of the orbicular structure in Corsica ; but in the granite of Kangasniemi in Finland, studied by B. Frosterus, and in the almost identical example from Mullaghderg on the coast of Donegal, the matter is now very clear. The chemical interchanges in

the molten and crystallizing mass may not be such as we can imitate ; yet they can be traced in all stages, from the inclusion of a flake of the altered clay-rock known as mica-schist to the development of a handsome spheroid with a radial structure in its outer zones, and a granular granitic core.

It is a case of the apple getting inside the dumpling ; absorption of the schist-fragment goes on until granitic matter actually takes its place ; yet it has caused a deposition of dark mica and of feldspars of the sodium-calcium series in zones as its material diffused outwards, meeting the granite " melt " and declining to be entirely removed.

While granite now occurs in the heart of many of the spheroids, others contain unmistakable residues of schist, which have controlled the general form of the spheroids by their flaky character. A shower of schist-fragments evidently fell from the roof of the cauldron into the bath of molten granite, and the interactions set up illustrate the phenomena of inclusion, concretion, and absorption.

All this is by way of encouragement to further observation. The small dome of Shap does not offer a good field for the study of marginal action, and we have far broader exposures of granitic cauldrons in our isles. At point after point along their moorland-flanks we shall find ample justification for the view that the crystalline rock granite, the granite of our polished slabs and columns, once lay in a molten state far down in the recesses of the crust.

CHAPTER VI

GRANITE IN GROWTH AND IN DECAY

WE have studied the general characters of granite, a very common stone in the earth's crust. It seems as if in every country, if we bored down far enough, we should come to granite. When lower portions of the crust are upfolded, or when upper portions are swept away by denudation, granite is the rock that comes again and again to light. Very naturally the older geologists looked on it as something fundamental.

This view is probably correct in its essentials ; that is to say, a layer of igneous rock rich in silica, potash, and soda, probably overlies, in the earth's general structure, a more dense envelope poor in silica and rich in iron compounds. Within this is the nickel-iron nucleus, the precise composition and physical state of which are still wrapped in an attractive mystery. Yet, when we come to examine individual granite masses, we find that they are intrusive rocks. They have come into place in a molten state and send off dykes and veins into their surroundings (Fig. 6). Locally, then, the granite is younger than the rocks invaded by it.

On the other hand, pebbles worn from a particular granite may be found in some still younger stratum.

Fig. 5. Weathering Granite. Three-rock Mountain, Co. Dublin.

Fig. 6. Granite intrusive in Composite Gneiss. Fintown, Co. Donegal.

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The age of intrusion must lie somewhere between those of the two systems of rocks concerned.

In the case of the greatest continuous mass of granite known to us in the British Isles, that which forms the high moors of Leinster, reaching from Dalkey Island for 70 miles south-westward to the junction of the Barrow and the Nore, the history of the intrusion is clearly known. The granite veins penetrate Ordovician shales and grits, and these were evidently arched in a long tunnel-like form as the molten mass came up from the depths. In adjacent parts of Ireland the overlying Gotlandian (Upper Silurian) strata, the age of which is known by their fossils, have been involved in the same system of earth-crumpling. It is safe to say that the Leinster arch is post-Gotlandian.

Old Red Sandstone beds have gathered unconformably on its western flanks ; they are laid down across the upturned and denuded edges of the Ordovician strata. Moreover, near Dublin blocks of the altered Ordovician shales and of the Leinster granite occur embedded in limestone of Carboniferous age. The upheaval and intrusion took place, then, in early Devonian times, and the conglomerates and sands gathered in the plains and lakes as the new highland came under the attack of rain and rivers. When the Carboniferous sea spread across the country, denudation had gone on so far as to expose the granite, very much as it is again exposed to-day.

The fact that the arch of Ordovician and Gotlandian strata originally extended across the ridge is clearly shown by surviving patches of the cover remaining on some of the highest crests. The granite, as we inferred in the less obvious case of Shap, consolidated under a

substantial roof. The length of Lower Devonian times may be estimated from the time required for the folding up of the range, the cooling of the granite, and the wearing away of the strata on its flanks to form a floor on which Upper Devonian forests grew. The remains of these forests, recording one of the earliest known floras of the world, occur in the freshwater Yellow Sandstone series of Kilkenny.

The noble masses of granite, surpassing the Leinster exposure in actual area, that spread inland from Aberdeen to the Cairngorm Mountains on the frontier of Inverness, cut the folded rocks of the Highland series and are also of Devonian age. The boss of Dartmoor in Devonshire occupies a dome in Upper Carboniferous and Devonian rocks, and is thus distinctly younger; while the granite of Goat Fell in the Isle of Arran, and those of the hearts of Mull and Skye, were intruded after the departure of the sea that deposited the white chalk against a northern shore-line in Upper Cretaceous times.

So much used to be said about the "primary" age of granite that it is well to bear in mind these British examples, which show that types of igneous rock are not restricted to particular geological epochs, but that they ooze up from the lower regions whenever opportunity occurs. The granites forming below us in crust-domes and arches at the present day are naturally not within our reach. They are still hot and viscid, and, even when their constituents ultimately freeze, long ages must pass before they are revealed by the removal of the cover under which they ultimately will cool. It is safe, however, to assert that a fused material capable of forming granite in due season underlies the Lipari Islands near Sicily at the present day. The pumice and obsidian, the glassy

rocks of modern eruptions in this area, have a composition the same as that of granite. This point may be illustrated by the two following analyses from Italian sources (E. Artini, *Le Rocce,* pp. 301 and 344, 1919) :

	Granite, Pelvoux, Dauphiné.	Obsidian, Lipari.
Silica	74·40	74·37
Alumina	13·91	12·65
Ferric oxide	1·39	2·58
Magnesia	0·28	0·20
Lime	0·61	1·22
Soda	4·65	3·87
Potash	4·36	4·57
Water	0·65	0·24
	100·25	99·70

Though the matter was for a long time obscured by classifiers of rocks in mineral cabinets in the last half of the nineteenth century, J. W. Judd and other English observers maintained the logical conclusion, which is now universally accepted, that granite is of all geological ages, and no date can be assigned to it except that of its last consolidation.

We say " last," because there is no doubt that molten masses were at one time more common in the crust, and perhaps generally nearer to the surface, than they have been since conditions settled down towards those that we now enjoy. Hence, by a gravitational grouping within a widely diffused " melt " in the lower layers of the crust, a very large quantity of granite was formed in very early times, while a very large quantity of rock-material more rich in iron was drained down nearer to the core. This explains the arrangement that probably exists in the crust at the present day.

The superficial sedimentary rocks are a sort of dust, worn by denudation from these primitive igneous layers. But again and again remelting has occurred, and the early igneous masses have renewed their youth. It is extremely doubtful if any part of the primitive crust of the earth remains in regions accessible to study ; and it may be asserted with confidence that none of the granite stones that we now handle ever belonged to that crust, except in the sense that their chemical constituents were constituents of the consolidating globe.

We have said in our previous chapter on granite that coarseness of grain is a sign of slowness of cooling and continuity of the right conditions of temperature. Pressure may promote the crystallization of most minerals ; but it is not likely to be a necessary factor in the growth of giant crystals. On the contrary, these giants arise where cooling of an igneous mass, and consequently, crystallization, are retarded. Greater depth in the crust means slower cooling and less opportunity for the escape of liquids and of gases ; the particles of any one mineral species have longer time to seek their fellows ; there is a longer epoch of freedom of path and movement ; and in consequence in the depths surprising developments take place. The laboratories where Nature manufactures giant crystals are now many miles below our feet ; in earlier times, when the whole crust, including the atmosphere, was hotter, the requisite uniform and continuous conditions were no doubt attained nearer to the surface. Hence truly coarse granites are to be looked for among exposures of very ancient rocks.

They are surprising enough when one comes across them in the field. In southern Ontario I have seen a

workman sitting inside a crystal of pink feldspar, which he was breaking up for the porcelain trade. In the same district crystals of mica had been found 9 feet across, and these had to be cut up in order that carts might carry them away along the forest tracks between the trees. Recently, W. T. Schaller has described crystals of spodumene, a lithium aluminium metasilicate allied to the common mineral augite, that are frequently 30 feet in length, sometimes 42 feet, and about 4 feet in diameter. These occur in veins of coarse granite in the Black Hills, South Dakota.

To cite a milder example, the granite of Ytterby, near Stockholm, is quarried for the sake of its feldspar, and the coarseness of the rock enables the workmen to throw the quartz, and some blocks where quartz is intergrown with feldspar, on to one heap, and the desired blocks of feldspar on to another. Few lands can compete with Scandinavia in the commercial utility, the variety, and the artistic beauty, of its granite stones, which all belong to early geological periods.

We have named some examples of granite moorlands in our islands. Let us come back to the ridge of Leinster, rising some 2,000 to 3,000 feet above the sea, and flanked by its Ordovician rocks on either side. The effect of the hot matter in the cauldron on these slaty walls is admirably manifest in the steep glen-heads of Wicklow. The rivers have cut ravines in the more easily dissected sedimentary rocks, which open out into wide basins on the uplands. As we pass up one of these valleys and approach the granite, the shales and slates are seen to be "mineralized" and crystalline. Plates of mica have developed freely on the bedding-planes, while in certain layers knots of andalusite and small red garnets attest

the loss of water and a rearrangement of the aluminous matter in the rock.

The mica is coarser as we near the granite margin ; the old clays are now represented by silvery and gleaming *mica-schists*. Their stratification, however, is not destroyed ; local crumplings may have set in, but the general trend of the strata of the Leinster arch, from south-west to north-east, is undisturbed. And then, as T. Weaver described a century ago in the mine-tunnels of Glenmalur, sheets of granite are found interbedded with the schist. The molten rock chose the bedding-planes as the easiest surfaces of invasion. The marginal strata opened up like the leaves of a book. A little farther, we find the layers flaked off and lying detached in a bath of granite.

Even then, the process has been so insidious, so devoid of swirling movement, that the trend, the " strike," remains the same. Layer after layer of sedimentary material is traceable as a dark band of mica-schist running through the crystalline granite. But in a few more yards, as we walk across some exposure on the now widened valley-floor, the independence of these sheets is lost ; they break up into micaceous strings, and then into mere flecks. The granite remains set with dark mica to an extent not met with in the ordinary rock ; though light mica may have developed in the schist, the complete reconstruction of silicates in the bath of granite has worked up the previously crystallized compounds and given us an excess of mica rich in iron. This is a very bald way of stating a complex series of reactions ; but the stages are unmistakable in the field. A new rock, called by some a " granitite," arises, through the mixture of the two rocks along the margin.

This darkened granite is seen for some distance inward from the junction, perhaps only for a few metres, while sometimes absorption has been more complete, and very little evidence remains of interaction. Yet the flecks of dark mica that give a special character to the grey granite of Newry, quarried on the upland of Armagh, are probably due to admixed fragments of Silurian strata, diffused with a fair uniformity through great masses of the igneous rock. We see the evidence in section as we pass across the flanking wall of a granite cauldron ; but we rarely get the more extended evidence afforded by the disintegrating roof. This region has been swept away by denudation, leaving the purer igneous mass exposed ; yet under the roof of the cauldron the process of absorption must have gone on over areas that could be measured in hundreds of square miles.

How far the growth of granite upward or laterally in the crust is due to the " stoping " off of blocks and their ultimate absorption in the mass has, like most problems where we cannot sit down and watch the process, not unnaturally raised some differences of view. The arch of Leinster may well have been moving upward through long epochs, and the liquid granite followed it upward as it grew. The domes styled *laccoliths* by G. K. Gilbert in his research on the Henry Mountains in 1877 are intrusive igneous masses bounded above by an upfolded stratum and resting on an undisturbed sedimentary sheet below. They are huge knots, as it were, in an igneous sheet that has spread along the planes of bedding ; they are swellings of the sheet where the beds above were squeezed up in a dome or were forced up by the expansive force of the gases in the intruder. But these " stone cisterns " are by no means of general

occurrence. Many of our domes of granite are like plugs filling an orifice, and cut directly across the structure of the adjacent rocks, sending out veins into them that merely fill irregular cracks, or penetrating sedimentary rocks, as we have described, along their planes of bedding (Fig. 6). In either case there is a marked tendency to the wedging off or flaking off of blocks into the cauldron.

If these are quickly absorbed, or sink into the depths, where they surely will be ultimately absorbed, there seems no limit to the growth of the granite so long as it retains its corroding liquids, ready to become gases, and its general fluidity under the influence of heat supplied. Among the pioneers of the " stoping " view of the growth of igneous cauldrons are G. V. Hawes (1881), in his study of the granite of Albany, New York State ; A. C. Lawson (1888) in his very memorable report on the Rainy Lake region of Canada ; and J. S. Goodchild (1892) in a paper on the Ross of Mull. But the French geologists, Barrois and Lévy, were among the first to open our eyes to the importance of the process, and no one has done more to develop it and to work out its logical conclusions than J. J. Sederholm among the antique cauldrons that are so widely and so well exposed in Finland.

There are still some who have doubts about the assimilation of other rocks by igneous masses on a large scale. Let us bias no one's mind beforehand ; let each observer go up to the mountains and ask his questions of the earth.

Granite stone very commonly forms mountains, because its massive and continuous nature prevents it from being easily swept away. Granites long exposed have been worn down in places, as in Finland, to a

hummocky lowland set with lakes, or to a forest-clad country of inconspicuous rounded hills, as in the "Laurentian Platean" of eastern Canada; but those more recently laid bare maintain themselves in crags and pinnacles. The young granite of the Mourne Mountains, probably of Oligocene age, is an example in our own islands; but older granites, long concealed, are sometimes thrust up into perilous positions by earth-movements of recent date. They still retain *aiguilles* and *arêtes*, veritable needles and knife-edges, beloved of climbers, such as those on the superb water-parting between France and Italy on Mont Blanc. Most of the Alpine granite was intruded towards the close of Carboniferous times, in huge cauldrons extending from Piedmont to Tirol; but its exposure at the present surface dates only from the early Pliocene period.

The mode of decay of granite is of considerable interest. Just as the chemical constitution of the molten mass provides a surplus of silica that separates out as quartz and profoundly influences the character of the stone, so the presence of potassium-sodium feldspar ultimately promotes its destruction in the open country and profoundly influences the mode of its decay. Even in cut blocks, corrosion occurs in the smoky atmosphere of towns, as may be already seen in buildings of the early nineteenth century. A polished surface, allowing no resting-place for rain, is obviously required as a preservative. On our granite moorlands, the passage of glacier-ice has occasionally worn so smooth a surface that decay is greatly arrested. But the growth of peat and heather after the withdrawal of the ice-front promotes acidity along every little

joint-surface, and natural acids, oozing in, begin the destruction of the rock.

The tors on Dartmoor, or Three-Rock Mountain (Fig. 5), those familiar jutting bosses, looking at first like mere piles of loosely fitting blocks, give us the clue to the origin of the boulders round about. "Rocking stones," delicately poised, and offering a temptation to strong and unscrupulous strangers, supply the link between the tor and the "clatter" on the moor. The flakes of granite at the tor-foot record both the physical and the chemical processes of decay.

These flakes can be easily broken in the hand. A sharp knock against a boulder makes the specimen fly apart along a multitude of cracks. The fragments can even be crumbled between our fingers; our hands are soiled with a white or yellowish dust.

A good deal of grit, however, is associated with this dust. The lustrous flakes of light-coloured mica come away unaltered from the rock. The dark micas have suffered in some cases; they are still flaky, but have become softer, dull, and greenish. The quartz emerges triumphantly in angular granules. It lies among fragments of feldspar as a resistant sand. It is the feldspar that has rotted and caused the ruin of the rock.

The powdery product of decay upon our fingers comes entirely from the feldspars. It covers the surfaces of their crystals and lurks in their cleavage-cracks, and the mineral not only breaks away from the rock, but also divides readily into little blocks. The weakening of this one mineral has set the others free. The granite flakes away in consequence, exposing new surfaces to attack.

The physical wasting of the massive rock is appreciated when we tap a boulder with a hammer. A sort of skin may be detached, parallel to the rounded surface. Brown stains of iron-rust show that decomposition and recomposition have been at work. The decay has spread inwards, and ultimately the big stone must crumble down. It is already a rough spheroid ; what was its original form ?

We look up at the tor and note the joints that traverse it, some due to shrinkage, as we learnt in the Shap quarry, some probably due to torsion. The shrinkage-cracks are frequently parallel with the original bounding walls of the cauldron, and rounded domes of granite, indeed the whole form of a moorland, are influenced by the form of the cover that has been stripped away. At times these broad surfaces of separation give granite a stratified appearance, and, with the vertical cross-joints, produce an impression of megalithic masonry. Closer inspection shows that many of the cross-joints are curved, as if controlled by the common tendency of contracting masses to form spheroids. One block, as it seems, pulls against another ; one secures a spheroidal surface, at any rate on one side, while its neighbour's side is concave. The mass cannot split up into independent spheres ; but, when a curved and convex surface bounds a block, this is perpetuated as flakes successively weather off it. The tor exhibits bouldery masses in position, ready to fall apart, and these become still more bouldery on the moor.

Moreover, any angular blocks receive the brunt of weathering influences at their solid angles, where three surfaces meet. These corners become rounded by decay, and a spheroidal bouldery form sets in here

also. The undermining action of decay along the joints, aided in our climate by frost-action, allows the outstanding masses of the tor to topple down; its relics in time are reduced to mere granite sand.

Where the widening of joints is due to the expansion of the mass under a tropical sun and its contraction again in the clearness of a tropical night, and where chemical influences due to the constant presence of rain are less important, wonderful curving surfaces arise, unencumbered by detrital soil. The control exercised by the internal jointed structure of the mass is here seen in the great features of the landscape; slabs of rock that have slipped down in landslides lie at the foot of slopes as smooth as those of ice-worn rocks, while huge blocks, rounded by the action of variations of temperature on their own surfaces, and to some extent by the friction of wind-borne sand, remain poised like rocking-stones on the crests. These fantastic landscapes are familiar in India and in Rhodesia; but we may see their fundamental cause in the jointing of our homeland tors.

The chemical decay that affects the feldspars, as we have already hinted, is a far more subtle influence than any physical attack. It is time that we looked into its details. For this, it is necessary to analyse the powdery product. It proves to have a definite chemical composition, and occasionally its particles assume a crystalline form. It is hence a mineral species on its own account. Usually, even under high powers of the microscope, this dust appears as mere tiny flakes with irregular edges. These flakes are crystalline, producing some effect on transmitted polarized light (p. 19);

but even this character is liable to be masked by their extreme thinness.

Fortunately, here and there, in cracks and cavities, samples on a slightly larger scale have been found. These are sharply bounded hexagonal plates, resembling tiny micas, and their optical properties have been studied. They allow a definition of the crystal-characters of the mineral *kaolin* or *kaolinite*, which proves to be a hydrous aluminium silicate with the composition $H_4Al_2Si_2O_9$. This formula is based on the determination of the constituents in the usual way as oxides, and a convenient mode of considering the silicate is to state the percentages of these oxides by weight. Let us compare them with the constituents of potassium-sodium feldspar similarly stated :

	Kaolin.	Potassium-sodium feldspar.
Silica	46·5	65·0
Alumina	39·5	18·5
Potash	—	12·0
Soda	—	4·5
Water	14·0	—
	100·0	100·0

The production of kaolin from such a feldspar implies, then, a loss of alkalies and of silica, and the retention in solid combination of some of the water involved in the attack. On the earth's surface the attack is due to rain-water. The mildly acid character of rain will be referred to when we deal with limestone (Chapter VII). The carbon dioxide of the air becomes carbonic acid in the water, and its action, long continued, breaks down the feldspar compound. The alkalies are carried away as carbonates in solution, leaving a certain amount

of silica free ; the whole chemical fabric is weakened and breaks down. Moreover, water containing sodium or potassium carbonate dissolves silica, and thus some of the silica present in the feldspar is carried off. The matter that remains pulls itself together in a new mineral form, the hydrous aluminium silicate kaolin.

Just as the quartz grains that are set free physically from the granite are the basis of common sand, so the kaolin formed by chemical interaction is the basis of common *clay*. These two dissimilar rock-constituents are liberated at the same moment on our granite moorlands. It remains for the separating processes of Nature to work on them day after day and age after age as they are swept down towards the seas.

The great deposits of kaolin-earth, so much sought after and so valuable as china-clay, are, however, not manufactured on the surface of the earth. They result from the action of penetrating gases and solutions, rotting the granite underground. Great masses become thus decomposed and weakened, as may be seen in the pits at St. Austell in Cornwall, and the mixed material quarried out is artificially washed until a clay of suitable fineness is separated from it. It is suggested that hydrofluoric acid, that powerful corroder of silicates, is an important agent in the subterranean attack ; but F. W. Clarke (*Data of Geochemistry*, 4th ed., p. 487, 1920) concludes that in all cases hot or cold water and carbonic acid are present and are efficient, whether at the moorland surface or in the laboratories underground.

A feature of the alteration of potassium feldspar that is well brought out by the microscopic examination of thin slices is the frequency of light mica as an internal

product of decay. Some authors have regarded this as a step towards kaolin formation, a sort of half-way house before the potash is entirely removed. The mica occurs in tiny wisps and patches, replacing a large part of the feldspar, the outer skin of the crystals remaining, as usual, more resisting. Undoubtedly this process of reconstruction, involving a loss of silica, implies a weakening of the mineral. When it powders down, tiny flakes of mica emerge, side by side with kaolin, and play their part in the formation of the mixed material known as clay.

In following so far the history of our selected stone, we have dealt with matters that seem in our day clear and obvious. The sediments of the sea-floor are uplifted ; molten matter follows them from the depths ; it sends off tongues and veins into its surroundings and melts them up, thereby adding to the igneous matter in the earth. The igneous rock cools, is exposed by denudation, and gives rise to new sediments by its decay. The highland is ultimately worn down, and the earth's surface is renewed by fresh upheavals. These considerations, however, remind us of a time when philosophy was not so tempered by observation, and when the fundamental rather than the recurrent nature of granite was a matter of mineralogical belief. The Scottish geologist, James Hutton, made a great step forward in 1785, when he observed the true intrusive nature of granite margins. In his day speculation was rife as to what were called the "revolutions of the globe," and it was held that the dignity of the Creator was most nobly manifested by sweeping catastrophes and coruscating reconstructions. Hutton, in his *Theory of the Earth*, brought together his conclusions as to the relations of

molten rocks to the sediments produced by their decay. He removed granite from its isolated and primordial position, and gave us the first conceptions of an orderly and oft-repeated sequence in the rock-forming processes on the earth.

CHAPTER VII

A LUMP OF LIMESTONE

THIS stone has a shell in it. There is no doubt about it. It is not the shell of a common snail, such as you may see sticking on the stones at the bottom of the garden. Nor is it merely attached by its own glutinous excretion—it is part and parcel of the rock. Look more closely ; here are broken bits of other shells. A large part of the stone must be made up of them. They are much like the shells that we gather when we visit the sea-side. But here they are, set hard and fast in a limestone block out of the quarry (Fig. 7).

The quarrymen have long noticed them, and they set aside the finer specimens for those who care about such things. Even the oldest of these workers, who goes back to a time when it was thought that men who laboured with their hands had no business to read, will tell you that " the sea was once in this place ; many a day I've said that over to myself."

The limestone that now makes the industry of the district, with its busy stone quarries and its fuming kilns as big as castles, was undoubtedly laid down in the sea. There is very little in it that was not once part of a sea-animal. Large shells may have become broken ; but many of them are well preserved, since they were filled up with mud before the soft deposit became uplifted by

earth-movements and consolidated into limestone-rock. This mud, when we study it closely, is composed of smaller shells, or broken bits of sea-urchins and sea-lilies, or delicate corals, preserving their partitions, which radiate from the margins towards the centres of their cups. Everything speaks to us of accumulation at the bottom of the sea.

A sea that gave so much shelly matter, and so little impurity of sand or mud, must have been pure and clean. The limestone was laid down at a long distance from the shore, or at any rate, away from large river-mouths. There is a third possibility, that the shore itself was a clean one ; limestone-rocks may have here abutted on the sea, and the older limestone in its decay had nothing to yield that would contaminate the water.

But why should not blocks of the older limestone appear as pebbles in the newer one ? Why should we not have a fragmental limestone-sand as a groundwork for the later shells ? Occasionally we do find something of this kind, and limestone-pebbles are quite abundant in many rocks formed by old torrents in the Alps of Switzerland. These limestone-conglomerates accumulated in regions where ancient limestones were being uplifted and attacked by weathering. Yet our marine limestone, and the great majority of such deposits, and even the sands of the shore in a region of mixed types of rock, contain scarcely any fragments of older limestone—for a reason that we may note hereafter.

The shell in the stone attracted us, and we may now come back to the composition of the stone. What is limestone ? Is it always made of shells ? In any case, shells must have the same composition as the limestone. Take a modern shell and test it.

Fig. 7. Shelly Limestone.

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The best thing is to treat it with an acid. Hydrochloric acid is a compound of hydrogen and chlorine, and may be called hydrogen chloride. In contact with a number of other substances, it breaks up and forms fresh chlorides ; the hydrogen is exchanged for something in the other substance. Hydrogen chloride dissolves in water, and the strongest solution that we can thus make contains 42·9 per cent. of acid. This is a very effective liquid, and we may as well add more water before we use it in our tests. Let us place an ordinary shell in an earthenware bowl and pour this dilute solution on it.

A brisk bubbling takes place, and the shell begins to disappear. The acid is dissolving it, and the shell is giving off a gas. This gas, if it is collected in a tube and tested, extinguishes a lighted match and has all the properties of what is known as carbon dioxide. The solution now gives a red flame if a drop is held on a platinum wire or an asbestos fibre in the almost invisible flame of a bunsen gas-burner. Or the solution may be made quite strong, that is, with a large amount of dissolved shell in proportion to the liquid used, and methylated spirit may be poured on it. Light the spirit ; it burns with a red flame.

Further tests familiar to chemical students may be applied. All will show that the solution now contains calcium. The shell was in part composed of lime, which is the oxide of the metal calcium, and the hydrochloric acid has formed calcium chloride, which is very soluble in water. Hence we do not see this chloride in the liquid used, and the shell-substance disappears entirely from view, partly as the invisible gas carbon dioxide, partly as the dissolved salt of calcium. Only a very small

residue may be left, from organic matter and from trifling impurities in the shell-substance.

The lump of limestone behaves in the same way as the shell. It gives off carbon dioxide, it dissolves, the solution reddens the flame ; and in both cases accurate analysis, by which we ascertain the proportions of the chemical bodies present, shows that the material under examination is calcium carbonate. This is only a somewhat more accurate way of saying " carbonate of lime," which should never be called " lime," a name that is reserved for calcium oxide. In popular usage, however, there is much confusion here.

Whence do the shell-fish, and the corals, and the hosts of humbler organisms, and the fishes with their bones, for that matter, obtain the calcium carbonate that protects or strengthens them while they live, and that remains behind on the sea-floor when they die ? Like ourselves, in the unconscious building-up of our hard skeletons, they obtain it with their food. Salts of calcium, mostly sulphate and chloride, are in solution in the sea. There is even a small amount of calcium carbonate. From these salts the animals derive the calcium which is deposited as calcium carbonate by organic processes during their lives.

A certain amount of calcium phosphate is also built up, and in clean dry bones this amounts to about 55 per cent., while calcium carbonate forms only about 7 per cent. of the bone. Some marine shells, such as those of the thin-valved brachiopods, Lingula and its allies, are built of alternate layers of calcium phosphate and a horny material, the latter predominating, so that the shells are slightly flexible. Some corals and some marine seaweeds deposit a little magnesium carbonate

side by side with a great preponderance of the calcium salt. But, from what has now been said, it is clear that the active life-processes of a great variety of organisms end in the accumulation of massive calcium carbonate, as limestone, in the final cemeteries of the sea.

Sometimes at the bottom of a lake, or of a lost lake over which brown peat has grown, a white powdery layer is found which the farmers use for "marling," that is, for adding calcium carbonate (so-called "lime") to their land. With the unaided eye, we may see that this white earth consists of delicate shells of molluscs that live in fresh water, and of rod-like bodies, which prove to be the remains of water-weeds that also stiffen themselves with calcium carbonate. So that limestones may also accumulate in fresh water by the growth and death of organisms.

Our lump of limestone is, however, compact and hard. It is all very well to say that it has been consolidated by pressure, when new material was laid down upon it and as it was squeezed in the mysterious movements of the earth's crust. Such pressure would have been strong enough to grind the shells into one another, and would have destroyed their forms; and even then some recrystallizing force must have set in to unite the particles into a solid rock. As a matter of fact, perhaps soon after the deposition of the mass, crystallization has been at work; crystals of calcium carbonate have been deposited between the shells; and the mass has been stuck together by a cement with the same composition as the hard parts of the organisms.

Calcium carbonate crystallizes in two distinct forms, so as to give rise to two mineral species, *calcite* and *aragonite*. Calcite is by far the more common, and may

be known by its easy cleavage in three directions, as we saw in Chapter II. This property is seen even in the hard parts of certain organisms, the sea-urchins and the sea-lilies, each plate or joint of which, though it has an outer form given to it by the organism, consists of a single crystal of calcite and consequently exhibits cleavage. In molluscan shells, however, the crystals of calcite are far smaller. Most molluscs, moreover, deposit their shell-substance as the mineral aragonite, in delicate fibres, and this material may be recognized by its greater specific weight. In aragonite there are more molecules of calcium carbonate, or more similar groupings of calcium, carbon, and oxygen—which proves to be a more correct mode of expressing the matter—in, say, a cubic millimetre than there are in calcite. A crystal of calcite may weigh 100 grammes ; one of aragonite of the same bulk would weigh 108 grammes. The specific gravities are as 2·72 is to 2·94. In shells they are somewhat less, owing to the presence of organic matter ; but the difference is quite perceptible and distinctive.

Experimentally, it is found that, when calcium carbonate is chemically precipitated from a solution of a calcium salt in water at a temperature near boiling point, aragonite comes down, while at lower temperatures calcite is precipitated, in delicate rhombohedral crystals, like well-faced bricks a little out of shape. In the sea, however, side by side, we have shells forming of aragonite, and others of calcite, and some with an inner layer of aragonite and an outer one of calcite. Corals make their skeletons of aragonite ; the oyster, unlike most molluscs, makes his of calcite ; the pearly nautilus precipitates aragonite.

In the same way, both aragonite and calcite may be

deposited chemically from sea water as a cement between the shell-fragments that form a limestone-mud on the sea-floor. The question of temperature seems to come in here, and aragonite is certainly the common product in tropical waters. In our own British seas, calcite is cementing modern shells into good grey limestone, as fishermen know in Irish waters, where large blocks of modern origin are caught up in the trawls. These are not so compact as the old fossil limestones, and a good many hollows remain in them unfilled ; but the making of the stone may be clearly traced. Why does their cement come down out of solution ?

We can understand that where sea-water contains calcium carbonate in solution and splashes over stones and shell-particles on a shore, the process of drying between the tides leaves the dissolved matter behind as a cement. But we must also remember—and we know it well when bathing—that the sea contains a lot of salts, mostly sodium chloride, and therefore cannot retain all that is offered it from the land. Calcium carbonate is practically insoluble in pure water ; about three parts go into solution in ten million parts of water. But when carbonic acid (hydrogen carbonate) is present in the water, a "bicarbonate" is formed, containing both calcium and hydrogen carbonates, and this bicarbonate is much more soluble. In this form calcium carbonate comes down in rivers to the sea ; but sea-water may soon acquire as much of this salt as it can hold, and a chemical precipitation occurs when more is offered to it. Here we have an origin for the cementing of limestones, even while they are gathering in the sea.

The excess of calcium carbonate may in places be brought into the sea by springs opening in its floor. In

other cases, since the deeper water, under pressure, is capable of holding more salts in solution, the carbonate is deposited when this water is brought by rising currents into regions of less pressure, that is, regions nearer the surface.

Ammonium carbonate arises from the decay of organisms, and this reacts on calcium sulphate and calcium chloride in sea-water, causing a precipitate of calcium carbonate in the condition of aragonite. Aragonite is thus at times added to limestones without the intervention of living organisms.

W. A. Herdman (Presidential Address to British Association, 1920) has recently called attention to the importance of the work of G. H. Drew, in discovering another mode in which calcium carbonate is thrown down. Drew shows that in warm shallow waters a species of bacteria, styled in consequence *Bacillus calcis*, destroys dissolved nitrates and nitrites and precipitates calcium carbonate ; so that, as Herdman says, " great calcareous deposits of Florida and the Bahamas previously known as ' coral muds ' are not, as was supposed by Murray and others, derived from broken-up corals, shells, nullipores, etc., but are minute particles of carbonate of lime which have been precipitated by tue action of these bacteria." Herdman points out the bearing of these observations on the origin of nfhossiliferous limestones in the sea.

In thin sections of marine limestone under the microscope, it is beautiful to observe the delicate fibrous crystals of calcium carbonate deposited between the tiny shells and between any fragmental grains. In the course of time, even the cavities of the larger shells that were not filled up at first by limestone-mud may

become choked and strengthened by a growth of deposited calcite.

In older limestones, a rearrangement of the calcite takes place ; a granular mosaic of interlocking crystals arises in the cement, and sometimes spreads into the shell-substance. The outlines of the fossils tend to merge into the ground in which they lie ; the smaller shells, such as those of foraminifera, disappear ; their mineral material has recrystallized in a granular form. Ultimately, even the larger fossils may become lost ; the rock is no longer a common limestone, but is now a crystalline *marble.*

Marble breaks uniformly in all directions, showing a structure much like that of a lump of sugar. It is thus available for carving and for statuary, since the sculptor does not run the risk of encountering flaws at the surface of fossil shells, or the possibility of a whelk or a mussel appearing where he proposes to shape the eye of Venus. The whole rock has become reconstituted, though its chemical composition and essential properties remain the same (see Chapter XI).

A curious point in such changes is that aragonite in the course of time becomes converted into calcite wherever water has access to the mass. Corals and shells that we know must have originally consisted of calcium carbonate in the denser condition of aragonite are found as calcite in all our older limestones. Clays manage to retain aragonite fossils through long geological periods ; but this mineral is evidently unstable, and calcite is its final stage.

The form of the fossil is not affected by this mineralogical change ; it is not a destructive alteration, like the slow development of granular calcite that converts the

limestone into marble. An interesting point at once occurs to us; since the fossils that were once in the aragonite state are preserved in all their delicate structure in the bulkier mineral calcite, some part of their calcium carbonate must have been removed; otherwise, they would have swelled up and perhaps become disrupted, mingling their outer surfaces with the groundwork round them. The presence of permeating, percolating, and dissolving water seems essential for a change of this kind.

The different kinds of limestone give us clues as to the past conditions of the regions where they now are found. The coral-banks above Cheltenham, or the compacter examples in the masses of the Pennine Chain, carry our minds to the wealth of animal life in the shallows of the tropic seas. The soft white limestone, the *chalk*, of Salisbury Plain is largely made of foraminifera and must have gathered as an "ooze" in a pure ocean. This ocean, when we trace the distribution of the chalk, is seen to have stretched eastward into Asia and north-westward to a shore-line somewhere across central Scotland. Its waters were pure, but not necessarily very deep, since the white chalk in the county of Antrim follows directly on beds of sand and conglomerate that show the characters of sea-beaches.

Off the west of Ireland, when we reach depths of 1,000 fathoms, deposits can be dredged up consisting almost entirely of foraminifera. These fine white muds are of exquisite beauty under the pocket-lens or microscope, and resemble in every detail the ground in which the larger fossils of our chalk formations lie. In the Alps we have crystalline masses, folded, streaked out, and crushed in great earth-movements, in which we have

little hope that organic remains have been preserved. Yet even here, in some fortunate exposure, traces of fossils may reveal themselves, and proclaim that the stone was of the same age as our chalk, and laid down in the eastward extension of the Upper Cretaceous sea.

The *oolites* are a very interesting type of limestone. The name is derived from the Greek *oon*, an egg, and *lithos*, a stone. (The second *o* in *oon* must be pronounced separately from the first, and the same must be done in the word *oolite* or " egg stone.") The groundwork of this rock is composed of little globular or ovoid bodies like the eggs of insects. Occasionally these " ovules " are larger, say a centimetre across, and more like peas, whence the coarser type of the rock is called " pea-grit." The " ovules " are here often flattened and irregular. It is clear that they originated in water, since they are associated with fossil corals and molluscs, and help to fill up the hollows of the shells.

Microscopic examination shows that they are not foraminifera. They are solid, except for a few branching tubes in some of them. In section, they are seen to be built up in successive layers, though this structure has been sometimes obscured by a radial grouping of the crystalline material. This material is calcium carbonate, and in ancient examples is in the calcite form. The oolitic grains have often suffered from recrystallization of their substance in a granular form, and may thus become merged, like fossils, in the groundwork of the limestone.

Some authors have seen organic features in these egg-like grains, and have regarded the tubules as a key to the whole structure. The grain, they have said, is formed by the cells of calcareous seaweeds, coiled up in

spheroidal groups. But others, with more justice, regard the tubules as accidentally included, or as resulting from boring organisms, and the grains as of inorganic origin. Foraminifera, blocks from sea-lilies, grains of sand, and all manner of fragments, are found shut up in the oolitic granules. In many cases, the granule has started as a deposit round about some such object as it was rolled by waves upon a shore.

Long ago in the West Indies, on the shores of coral isles, oolitic grains were found to be in process of formation. The material of these modern examples is aragonite, though it has become changed to calcite in our older limestone masses. It is no doubt deposited chemically from the sea-water, where an excess of calcium carbonate is present; this may be caused by the evaporation of the water on the beach, or through the relief of pressure on water rising from below, or even with the aid of bacterial action. But an important factor in the deposition, promoting the formation of aragonite and not of calcite, is no doubt the reaction already mentioned of decaying organic matter with calcium chloride and calcium sulphate.

The rolling action of the surf prevents any one grain from growing much larger than another; there is a competition among a host of moving nuclei for the calcium carbonate that is coming out of solution. This marked uniformity of structure gives oolitic limestones an advantage for the builder. When not too rich in large shells or corals, they may be easily trimmed in any direction. The stone of Caen in Normandy and those of Portland and of Bath have become famous in the history of English architecture.

The Normans imported Caen stone for their great

cathedrals; and Sir Christopher Wren rebuilt the London churches, including St. Paul's, after the great fire of 1666, with a lavish use of oolite from Portland. Even in Dublin, where grey limestone of an older geological period is quarried close at hand, the fine classical buildings of the eighteenth century were adorned with columns and entablatures of Portland stone, the product of waters beating on coral strands when the warm Jurassic sea spread across the English midlands.

The compactness of limestones in general, and their uniformity of grain, cause them to break along great continuous joints when they become twisted, like other rocks, in the earth. The soft beds of the sea-floor have become cemented; they have been covered by strata of many diverse kinds; they have been lowered towards the depths—which, after all, are not so very deep when compared with the great radius of the earth—and they have been brought up again towards the mountain heights. These movements warp and strain the mass, and it cracks through its thickness of three thousand feet or more. The regular joints thus produced are well known to the quarrymen, who wedge out their blocks along them. Two series of joints, roughly at right angles, and both again roughly at right angles to the planes of bedding, are waiting, as it were, to help the working of the stone.

The bedding shows itself wherever some slight change, a run of mud or sand, or even a zone of coarser types of fossil, has occurred to break the uniform character of the massive limestone. But the bedding, or stratification, is less important than the joints, which lead to the formation of steps and ledges when the rock comes under weathering in the floor of streams or on the free hillside,

and which often form the faces of huge scarps that block our progress across a mountain.

Hence it comes that some of the most imposing scenery of the world is formed of massive limestone. The chemical and physical characters of the lump that we gathered as a sample in the hand impress themselves on the surface of a mountain region. The rock breaks ; but it is not washed down in powder, like the yielding shales or crumbling sands. The freezing of water in the cracks wedges off great blocks, which leave a sheer face, the joint-face, on the wall behind them. Frost-action is a feature of temperate climates ; yet in arid regions limestone breaks down in the same way. The wind may carry up abrasive sand against the hillside, and this also works along the bedding and the master joints. The undercut rock breaks off along a joint-face ; the fragments resulting from its decay and downsliding are blocks as big as houses.

Moreover, the rock is acted on by solution. It absorbs water, and this water is not absolutely pure. It has desceneded from the atmosphere in the form of rain, and has absorbed carbon dioxide as it fell. Minute quantities of nitric acid, and sulphuric acid to a larger extent near manufacturing towns, are also gathered by the rain. Carbon dioxide is always present, and the mildly acid water attacks the surface of the stone. The soluble double carbonate is formed, and to some extent the still more soluble sulphate, and these are carried away through the pores of the rock and down the joints. We now see why fragments of limestone are not delivered to the sea-beaches, or found in ordinary limestones accumulated off the shore. As the water trickles in, the joints themselves are widened ; from barely traceable

cracks they become dangerous and gaping grooves.

Limestones are often so pure that they leave very little soil behind ; the few grains of mud or sand set free are quickly swept away by wind. Hence a high limestone mass preserves a plateau-structure. Its surface may be that of an uplifted bed, and where the beds are curved and bent the hill-slopes often follow the planes of stratification. Where an arch or dome has been eaten into, the edges of the uptilted strata stand out as abrupt scarps on either side. The absence of soil leads to an absence of vegetation. Thin grass, suitable only for sheep-pastures, may spread across the upland here and there ; but over large areas the rock remains bare and wind-swept, and plants must be looked for in the crevices rather than on the surface of the earth.

No streams run upon this surface, for the water has gone down vertically among the cracks. Some of these cracks have been widened into veritable valleys, and the water appears along their floors, perhaps thousands of feet below the plateau on which we stand. It may still be working its way downwards as it flows, or it may have reached a level where the rock-mass is waterlogged, and what we then see is the general water-surface, or "water-table," becoming visible along the groove.

The drainage of limestone is indeed largely underground. The Slavonic shepherds of the lands east of the Adriatic have given the name *dolina*, meaning a valley, to the vertical shafts down which the water runs. These are widened out by solution at their tops in funnel-like forms, and are well known as "swallow-holes" to farmers in our Yorkshire plateaus or on the broad uplands of the chalk. Sometimes they originate with some abruptness from the falling in of a subterranean

water-way, and many of the fine and steep-walled gorges in limestone areas were in the first instance hollowed out underground, until at last their roofs collapsed, letting in the light of day. This is clear from the fact that here and there "natural arches" remain across them, as in the romantic gorge on which the Algerian town of Constantine is set (Fig. 9). No surface-stream can have channelled out the ravine in the limestone and at the same time have left a bridge of the same rock across its course.

The work of water within the limestone is seen in the frequency of caves. The openings into these are discovered in many cases by chance, and some adventurer forthwith starts an exploration. A fascinating underworld opens up before him. Water may be heard flowing far below, and he may walk along some deserted channel that is now absolutely dry. Huge halls are encountered, where the roof represents the first level of excavation, and the floor the last before the water escaped to passages still farther down. In many cases water still covers the floor to dangerous depths, and collapsible boats have been devised for what has become a specialized type of geographical research. When, with the aid of a compass, the caverns have been mapped out, they are again and again seen to form a roughly rectangular network, with expansions here and there at the crossing of the ways. The joints of the limestone have controlled the passages of solution ; the characters of a small block, a limestone stone, are accountable for the noble landscapes that we here discover underground.

The fact of the solution of the limestone in natural waters is again and again brought before us as the water dries. Where it trickles out on the face of some open

Fig. 8. Limestone Terraces of Hot Springs. Hammam Meskutin, Algeria.

Fig. 9. Arch across Limestone Ravine. Constantine, Algeria.

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valley, along which, perhaps, a main road has been carried as the only means of dealing with the dissected upland, the ferns and grasses may be found coated with a white deposit, *travertine* or *calcareous tufa*, representing what has been carried in solution from the limestone mass. Twigs dipping into streamlets may become thus coated over, and sometimes an oolite arises, or rather a pea-grit, from the continuous deposition around rolling stones.

Travertine may grow to such an extent that it forms a floor to the stream and raises its level in the groove. The water builds up new limestone and chokes its own ravine. At Jajce in Bosnia, a barrier has been formed by the water flowing from the Pliva lakes, where it emerges on the hollow of the Vrbas, and the side-stream has been so uplifted that it joins the Vrbas by a noble group of falls.

This is only a subaerial development of what goes on in limestone caves, when water still can trickle in, evaporating while it falls. Beautiful pendants of calcium carbonate hang from the roofs, and beneath them the dropping water forms domes and cones that in time unite with the pendants as pillars and screens from floor to roof. These are the well-known *stalactites* and *stalagmites*, which ultimately tend to choke the caves. Reconstruction thus goes on in the hollowed mass ; a new limestone of purely chemical origin strengthens the rock underground, while the swallow-holes are still developing on the exposed plateau overhead.

Where hot subterranean waters traverse limestone and emerge on the surface of the earth, the formation of travertine is far more conspicuous. The pea-grit of aragonite in the gorge of Karlovy Vary in Bohemia is known to hosts of visitors to the springs. The Mammoth

Hot Springs of the Yellowstone Park have built up a series of basins on the hillside, as the orifices became successively choked and their places were taken by others higher up. Such tiers of basins, one above another, their edges thickened where the water runs over and deposits a stalactitic fringe, are typical features of what we may style volcanic springs.

Freshwater algæ, giving variegated colours to the limestone, abound in the hot waters, and their growth, demanding carbon from the dissolved bicarbonate, splits up this compound and leads to more rapid deposition of calcium carbonate. The carbonate, owing to the high temperature, very commonly forms an aragonite and not a calcite travertine.

We need not go as far as Wyoming to see deposits of this kind in all their beauty and their freshness. At Hammam Meskutin, a few miles west of Guelma in Algeria, the subterranean waters, emerging with a temperature of 97°C., have built up an exquisite rock-cascade (Fig. 8). At the crest, the water bubbles out, forming little cones of travertine, with thin and fragile crusts. In time these thicken ; they choke their vents ; and a well-known group on the adjoining plateau stands up as massive pinnacles. Over the slope, which is now shaded by eucalyptus trees at its foot, the steaming water flows from basin to basin, and the broken sunlight gleams on milk-white terraces, stained here and there with ruddy brown. The limestone within the Atlas ranges is yielding up new limestone at the surface.

We have travelled some way from the cold grey quarry in the homeland ; but travel is the very essence of our study—the common stones have once more led us out to the fairylands of earth.

CHAPTER VIII

A FLINT

ROUND about London, Salisbury, Norwich, or Bridlington on the Yorkshire coast, the surface-deposits contain quantities of flints. We do not speak of flint-rock, but of "a flint." It is an object by itself, with an immense variety of shapes, but never with a crystal-form. Its interior is sometimes dull and porcellaneous, sometimes black and shining. In the latter case small chips are translucent, and very sharp upon the edge. The flint is brittle, but it has no regular cleavage ; fractures often show curving surfaces, like those of the interior of a shell, and a sharp stroke, delivered at one point with deftness, may cause it to break from that point along a conical surface, so that a form like the shell of a limpet is produced. Such cones on flint may be picked up now and then from the material broken casually for the roads.

The outer surface of a flint is duller than the inside. It may be pure white, or brown with iron rust. The brown tint may extend into the interior, but represents a staining that has spread. The brown flints have come from the gravels ; those with white exteriors are freshly extracted from the chalk.

Curiously enough, the foraminiferal limestone known

as chalk, a rock so soft that we can write with many specimens on a blackboard, almost as well as we can with its commercial imitations, is the natural home of flint. The places named in the first sentence of this chapter have chalk close against their doors. But flint has a character that enables it to be diffused, as it were, far beyond the limits of the rock that gave it birth. It is so hard—and herein lies its startling contrast with the chalk—that thousands of feet of the limestone may crumble or dissolve away, while the flints will yet remain, cumbering the surface, with some slight decomposition on the outside in the course of ages, but with practically the same shapes as those given them in the chalk.

Flint gravels are thus known in many regions where the underlying rocks are absolutely devoid of flints. The streams lay hold of the material, and in time the flints, jostling against one another in their travels, may become rounded into beautiful little pebbles, like those of the sandy beds near Woolwich, or of the cemented "pudding-stones" of various lands. But in most cases they tend to accumulate in the soils, knobbly and resistant, and survive the rude blows and insidious chemical reactions whereby other rock-material is destroyed.

Flints are thus found in unexpected places. They can be dredged up from the Atlantic off the coast of Ireland, or gathered from the surface of islets from which any covering of chalk has long since disappeared. Great irregular unrolled lumps, with the characteristic white surface and gleaming black interior, lie in the detrital clays on the coasts of Waterford and Wexford, and must have come, at no very distant geological epoch, from lost land lying to the south. The beaches of the Isle of

Wight or Dover, or under the allied white cliffs of France, attest the resisting powers of flint, where the edge of the land goes down before the battery of the sea.

So far we have been talking about flint and chalk without looking at the two of them together. In quarry or scarp we may appreciate their association and their contrast, and best of all, certainly, in the great walls along the coast. What first strikes the eye is the arrangement of the flints within the rock. Great continuous lines of flints, which are the edges of layers running through the mass, occur at intervals of, perhaps, two or three feet. They lie horizontally in the cliffs, or bend up with the planes of bedding where these have been uptilted. In the steeply dipping strata of Dorsetshire or the Isle of Wight, the flint layers are in places absolutely vertical.

Where shall we begin our study? With the broad structure or the intimate detail of the rock? The broad structure is in this case entirely deceptive. Our first notion would be that the flint layers are akin to conglomerates, and represent stony material washed in at successive stages during the accumulation of the chalk. Very slight observation of detail challenges this view; the flints are not rounded; they are not pebbles, and their irregular projections are thrust out, as it were, in all directions across the general bedding of the rock (Fig. 10). Even if this were not so, it would be very difficult to account for the periodic invasion of the sea by floods or ice-rafts capable of bringing in such lumpy materials and casting them down into the depths.

Come, then, to the details. Many flints contain fossils shut up in their hard substance—fragments of the easily broken fibrous shells of the mollusc known as

Inoceramus; or sea-urchins, fragmental or entire; or Terebratulas, shells that, with the large perforation in one of the umbos or "beaks," resemble so charmingly antique lamps with lids on them. But, most commonly of all, we find traces of the delicate mesh of sponges (Fig. 11).

Sponges are not all horny and flexible, like those that are torn from the sea-floor to satisfy man's desires and the demand for comfort in the bathroom. The domestic sponge, indeed, represents two genera only of an extensive and a highly antique race. Some sponges have delicate three-rayed spicules of calcite set in their animal substance, no doubt as a protective strengthening. In others, and notably in a great series of fossil forms, the calcite spikes are closely matted together, and a solid tubular or cup-shaped skeleton is built up. In others, like the exquisite Euplectella, known as Venus's flower-basket, a delicate mesh arises, formed of six-rayed spicules united regularly by their ends, and these spicules are made of silica, secreted by the sponge-material from solution in the sea. A great variety of siliceous sponges occurs, especially in limestone strata from Carboniferous to Cretaceous times. The association of these abundant fossil forms with limestone shows that they throve in pure waters and often at considerable depths.

Even in fragments, where we cannot be guided by the general branching or cup-like form of the sponge, the delicate meshwork of the skeleton may be revealed. In very many flints, hollows are found, containing white powdery residues of sponges, and retaining something of the general form, as if the flint had grown around the sponge. In some combe-bottoms of the Sussex downs, where the white-coated flints have accumulated as a

Fig. 10. Flint in Carboniferous Limestone. Ireland.

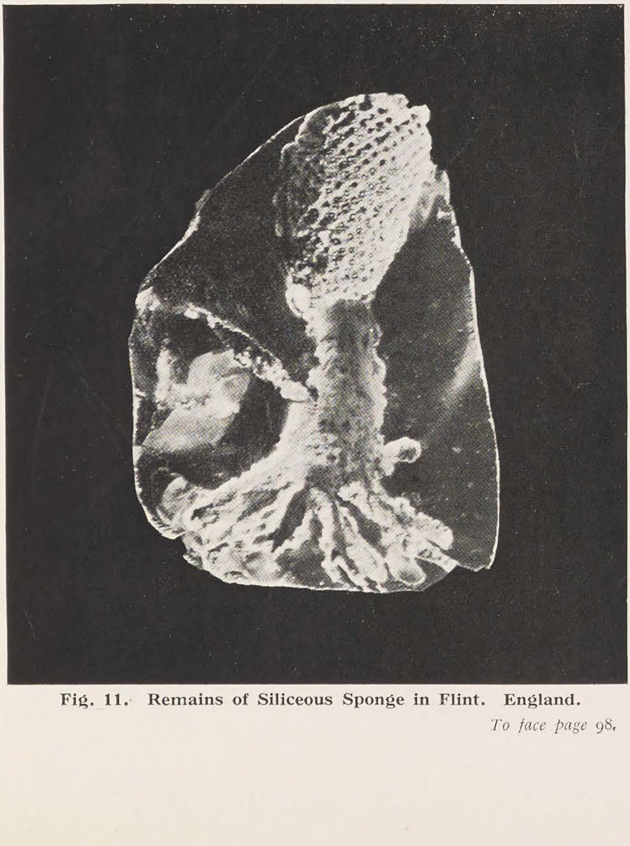

Fig. 11. Remains of Siliceous Sponge in Flint. England.

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gravel, almost every one of them reveals on fracture some cavity with traces of a sponge (Fig. 11). It is suggestive that in many cases the sponge-material has been dissolved ; but portions of the mesh, such as the folded wall of Ventriculites, are often seen in the solid flint. May not the flint, then, represent silica which was in some way derived from the solution of sponge-spicules? Such a solution of the meshwork has evidently gone on.

But here we must remember the relation of the flint-zones to the chalk. No geological problem is to be solved by the chemist or the microscopist alone. The bands of flint on the great rock-faces follow the planes of bedding and were clearly formed before the bending of those planes. Hence the flints resemble objects which grew on the sea floor and were, level after level, successively entombed in the soft foraminiferal ooze. Do the flints themselves represent zones where sponges were specially abundant ?

The matter is worthy of consideration, if only as an example of scientific reasoning and research. We ask at once another question ; why should sponges blossom out at a certain level and then apparently die away ? Why should they then recur after an interval of many years ? For a foot of foraminiferal ooze does not accumulate quickly, and in this intervening foot, or perhaps for eighteen inches or more, no flints have been formed.

Fantastic suggestions have been made, even by scientific workers, as to the nature of the flints ; that they were themselves sponges, although in thousands of examples they are the envelope that has gathered round a sponge ; that they were gelatinous masses of silica, perhaps in some way connected with an organism of

irregular form, or perhaps of inorganic origin, which clustered on the sea floor and became entombed in limestone-mud; that they represent hollows in the chalk from which calcareous matter was dissolved away, and which afterwards became filled up by silica. This last view is in complete defiance of all that is known about flints in the field and about their relation to the fossils which they enclose. In fact, flints are such familiar and yet such puzzling objects that a large number of persons, ordinarily engaged in other lines of thought, have expressed dogmatic opinions on them, and have wrapped the question of their origin in an entirely unwarranted amount of mystery.

Not only do flints enclose fossils, but they fill up the interiors of fossils and make internal moulds of them. Not infrequently, in a roadside heap, we may find a cast of a sea-urchin. Even the small pores in the shell through which the tube-feet of the animal were worked by muscles are represented by solid pimples on the siliceous cast; the flint has therefore penetrated the pores. Now and then a flint contains an internal cast of a sea-urchin which is separated by a hollow space from the surrounding flint. A perfect mould of the exterior appears on this outer flint, while a perfect mould of the interior lies loose inside. The shell of the sea-urchin has disappeared.

What generally fills the cavities of fossils embedded in the chalk? The chalk itself, the foraminiferal ooze. The flint in the cases just examined clearly represents this ooze. This is a very important step in our enquiry. The flint, far from being itself a sponge or, indeed, any kind of organism, must result from alteration of the ooze.

Silicified limestones are quite common. In the

Pacific Ocean at the present day the aragonite of coral skeletons becomes dissolved and, particle by particle, becomes replaced by silica. Fossil corals, now represented by flinty silica, are common in our Carboniferous limestone; and thick beds of flint, often called chert, have replaced corresponding beds of limestone. The mystery is in the chemical replacement, a mystery common to most chemical reactions. If the speculators about our chalk flints in the south of England had studied flint over a wider field, many wild theories would have died a natural death.

As a matter of fact, C. G. Ehrenberg, of Berlin, observed with the microscope traces of minute organisms in translucent flakes of flint as far back as 1838. These organisms are the same as those of the original oceanic ooze. Sponge-spicules are represented in flint by material, earthy calcite or the green silicate glauconite, which at one time filled up their tubules and took internal casts of them. Foraminiferal shells that were clearly once in a calcareous condition are here seen in the form of the hard material flint. The flint is thus in all its details a replacement of the limestone-ooze.

Thin sections, successors of Ehrenberg's flakes, amply justify this conclusion, whether they are taken from nodular flint or from that which forms moulds of the interior of shells. Spicules of sponges are commonly apparent, but these, as above remarked, are not the original siliceous spikes. Their silica has gone into solution, and is now represented, together with that from a host of other spicules, by the minutely granular and crystalline substance of the flint.

Another point is here suggested. The silica of the hard parts of the sponges is not crystalline. We know

this from its having no effect on polarized light under the microscope. It behaves like opal. The silica deposited as the skeletal parts of organisms, in sponges, radiolarians, and the cell-walls of the minute plants known as diatoms, is, in fact, in the opaline state. Flint, on the other hand, shows no external crystal-form, such as we know in quartz, but consists of a multitude of irregular crystalline grains, packed closely against one another. Now and then a fibrous structure is apparent—the individual fibres, like the granules, reveal themselves by their action on polarized light—and this is the typical structure of the massive mineral styled chalcedony. Flint is only a commonplace chalcedony.

The white outer surface that is so conspicuous in flints when we pick them straight out of the chalk is not a coating of white limestone. It will not bubble up with acid, and it has been ascribed to less complete deposition of silica during the last stages of flint growth; but it probably represents the loss of part of the substance of the flint. Instead of remaining translucent, and therefore dark as the light penetrates the mass, a multitude of reflections takes place from the surfaces of granules that have air and not flint as part of their surroundings. The same difference is seen between pumice and obsidian. Pumice, the froth of the glassy lava, is light-coloured because of the abundance of reflections from its pores; it is the same substance as the natural black volcanic glass obsidian. Melt a piece of pumice and you get rid of the internal air-spaces; a continuous lump of glass results.

Flints seem to suffer a certain amount of attack in the waters that permeate the chalk. In some surface-

gravels, this attack has gone so far as to render the smaller flints powdery throughout. When first formed, however, they were no doubt continuously compact.

The ideal flint should be spherical, growing evenly round some centre that induced the change ; but the conditions of removal and supply have rarely allowed of this. The fantastic forms that seem to imitate birds, human limbs, and Polynesian images, thus affording endless fascination to unwary collectors, are due to irregularities of growth. Since the flint replaces so much limestone, it may grow in any direction ; it is not necessary for it to lift the load above it ; the rock dissolves as the particles of silica arrive.

Now we can review the full cycle of changes, and it is surely remarkable enough. Associated with the calcareous shells, mostly of foraminifera that accumulated in a slow but steady shower on the bottom of the ancient sea, were organisms that made siliceous skeletons, just as happens in our oceans at the present day. These skeletons were formed of opal. Opal is not so stable as chalcedony, and in time the remains became dissolved. Water in the rock-mass took back what the organisms had extracted from the water of the sea. From some cause this water became overcharged with silica at certain levels, and matters were adjusted by a solution of the limestone and a deposition of chalcedonic silica in its place.

The mystery, then, is not in the forms of the flints and their contrast with the adjacent rock, but in the phenomena of replacement and precipitation, phenomena common to most cases of "concretions." The more we study mineral concretions, which often differ so markedly from the rock in which they lie, the more we

realize that something has been carried away and that something else has been deposited in its place. The most difficult cases are presented by the perfect brassy cubes of pyrite, iron disulphide, that occur in slates (p. 118). The great flattened spheroids of iron carbonate that are, as it were, embedded in our Carboniferous strata represent growths during the consolidation and rearrangement of chemical constituents in the rock. In flint the actual replacement of one material, particle by particle, by another, is especially apparent; but the fundamental problem is the same.

It is hard to think out what happens during the consolidation of a series of marine deposits. We must remember that our first observations in the case of flint, our observations on the white walls of Albion, showed us that we have to deal with fairly early epochs in the history of the limestone, before it underwent warping and crumpling in the earth. It was drying—of that we may be certain; and the saline water of the sea was draining out of it. If the sea-water had merely evaporated, it would have left great beds of common salt. There is, then, every probability that, as a mass of marine strata is raised by earth-movement, water drains away through it, promoting reactions as it goes. There is no longer a competition among marine organisms for certain of its ingredients. The water may become more highly charged with silica and salts of calcium as it moves downwards and outwards through the mass.

R. E. Liesegang, of Dresden, has shown in recent years how a solution diffusing outward and encountering something with which it reacts and forms a precipitate, moves on into this medium until a concentration

sufficient to cause precipitation of the particular salt occurs. A zone of precipitate is thus formed, through which the first solution penetrates until the conditions are repeated, and a second zone of precipitate is thrown down. Zone after zone may thus arise as diffusion goes on, so long as a supply of the first solution is assured. In this way Liesegang explains the banding of agate, and a number of geological features involving rhythmic repetition.

He then suggests (*Geologische Diffusionen*, p. 126, 1913) that even the zones of flint in limestone may be phenomena like those which he obtains in his test-tubes with a solution of silver nitrate acting upon ammonium dichromate in the interstices of a jelly. The precipitated bands of silver chromate thus illustrate what has occurred in Nature on a gigantic scale, when water charged with silica diffused through the porous masses of the chalk.

This question has been taken up by W. A. Richardson ("The Origin of Cretaceous Flint," *Geol. Mag.*, 1919, p. 535), who shows that there is a much higher percentage of silica diffused through the lower part of the English chalk, in which flints have not developed, than in the chalk where flint-zones are frequent, and that the silica in the total flint-zones, if diffused through the associated chalk, would give a quantity of much the same order as that in the Lower Chalk, namely, 2 per cent. He concludes, then, that the silica of the flints, as W. J. Sollas has always maintained in his studies of fossil sponges, was derived from the solution of siliceous skeletons in the chalk and became concentrated in the present flint-zones. Its precipitation has not, however, depended on the abundance of sili-

ceous organisms at particular levels—a grouping always very difficult to explain—but on laws of diffusion and concentration comparable to those that Liesegang has studied experimentally in his laboratory tubes.

Though traces of sponges are so commonly associated with flint, calcareous moulds and replacements of siliceous genera are found at all levels of the chalk. The frequency of these moulds, indeed, attests the prevalence of solution. The opaline skeletons of hosts of radiolarians and diatoms, minute organisms that are rarely traceable in chalk, have no doubt disappeared altogether in solution, and are now represented, with the silica of the sponge-spicules, in the less beautiful but more stable form of flint.

Some solution and deposition went on even after the rock set fairly fast and was capable of cracking, as is proved by the occasional occurrence of flaky bands of flint in joints, and the re-cementing of flint nodules that have become broken during stresses in the earth ; but the main regrouping of the constituents of the rock took place during its first consolidation, and the process, geologically speaking, may not have required many years.

We are still some way from discovering the precise chemical reaction that produced these great results. The silica was there, the calcium carbonate was there ; but what promoted the exchange ? Suffice it for the present that observation in the laboratory and the field have removed a host of ill founded fancies that gathered round the name of flint.

It takes a long time for the swirl of waters to make a true pebble out of flint. In most of our gravel-pits

much of the material is still angular. The flints on the surface of the sands and clays of the New Forest must have been transported from a distance, since they originated in chalk strata, which underlie the sands and clays and are exposed in the north of Hampshire or southward in the Isle of Wight. Yet, as cyclists and motorists know, it is not the malignity of the road-menders that makes these flint fragments cut like knives. Primitive man noticed this feature of flint, especially when he walked across the gravels barefoot. The sharp cutting edge of a naturally fractured flint suggested his first weapons and his tools.

From throwing any stone that came handy, he took to throwing sharp ones, and he chose forms that were sharp on one side and knobbly on the other, so as to give a good grip to the hand. Such flints could be held and used for all the purposes for which we now use knives. In time they got broken, and were, by accidental fracture, occasionally better than before. Man then set about breaking flints, so as to improve on Nature. The earliest forms were rough, the so-called " eoliths " of collectors ; but the making of scrapers for cleaning skins, of flint spear-heads and of knives, must have spread quickly when the art was once discovered. Splendid elongated forms, chipped away along shell-like curving fractures over their whole surface, may be collected from the gravels of the valleys of the Thames and Seine, and they show how human industry developed a type that for century after century held its own.

In the comparatively refined days of the later Stone Age, when the larger tools and weapons were made of stones that could be ground and polished, so as to have

a smooth surface and a sharp edge just where needed, flint was still used for knives and arrow-heads. The bow had been invented, and the small flint flake, leaf-like in form, and trimmed to a cutting edge all round, was fitted in the slot of a wooden shaft, and very likely tied there with a thong, a miniature copy of the spear. As a further improvement, the flake was chipped carefully out so as to yield a barb on either side, and such arrow-heads were no doubt specially prized and became articles of trade.

The sites where Stone Age workshops were established are known in many places in our isles. A great loss of material was incurred in working, and the implements that we now gather are often defective samples that were cast aside. But flint was cheap and abundant, and had been already quarried by Nature out of the parent chalk. The gravel-pits and sea-beaches gave an endless choice, and the peoples that did not possess flint were no doubt at a social disadvantage, being dependent on others for what became a necessity of life.

Quartz, obsidian, compact basalt, satisfied the needs of some ; but the militant spirit and the disciplined forces of destruction were fostered to the full by the prevalence of munitions on the chalk. The great earth-rings on the Wiltshire uplands testify to a warlike population ; readiness for defence implies the readiness of others to attack. The internecine feuds of these early British folk, Mediterraneans conflicting with long-heads of a Nordic stock, may have ceased for a time in the swirl of some great invasion. The despised eastern peoples, who had to buy their flints, in time smelted copper, and then hardened it with tin. Perhaps

the tin ores of Britain were ignorantly bartered on the coast, until the day came when the fleets returned with sterner purpose, and the cunning arts of the Stone Age went down before the sword of bronze.

CHAPTER X

ROOFING-STONE

THE stratification of a stone depends on various causes. In considering the sand of the shore (Chapter III), we noted how a rock-mass may be built up of layers differing in fineness of grain ; and how a little mud run in from the coast may produce a change that emphasizes the bedding in the rock. Even a number of shell-fragments, spread out with their flat surfaces in parallel planes, may allow a rock to split and so reveal its layered structure.

A rock that separates well along its surfaces of stratification into slabs two inches or so in thickness is useful as a flagstone for street-paving ; a rock that splits still more delicately may be useful as a roofing slate.

In the beautiful old villages built of local limestone in the Cotswolds, even the roofs are commonly made of sandy limestone. Certain flaggy beds exist among the marine strata of the hills, one series of which is known as the " Stonesfield Slate," from the village of Stonesfield west of the great park of Blenheim on the Oxford and Worcester road. W. D. Conybeare and William Phillips, in their *Outlines of the Geology of England and Wales* (p. 204), well described the workings here in 1822.

Two beds of buff or grey oolitic limestone are sought for, each about 2 feet thick, and the operations in the little valley honeycomb the hillside and have quite the character of mines. John Phillips (*Geology of Oxford and the Valley of the Thames*, p. 237, 1871) furnishes another picture. The fossils of the series in which these well-stratified beds occur appeal to him, and he reads through them the origin of the limestone. He sees, where the stream-cut vale descends towards the Evenlode, the edge of a warm sea in far Jurassic times, where "the Stonesfield lagoon, full of fishes and molluscs, receives with every cyclonic storm drifted branches of cypresses and swarms of wind-wrecked insects, while the swollen land-streams bring down, but not with equal rate of motion, the bony remains of amphibious and terrestrial lizards, which perished on the banks and river beds, and the bodies of small mammals which had sported in the trees. Not far off were coral reefs, and great beds of shells, and fishes, and over all

> '. . . adsunt
> Harpyiæ, et magnis quatiunt clangoribus alæ.' "

The reference to Vergil's harpies is here, of course, to the flying reptiles of the period. Those represented at Stonesfield are not so very terrible, and hardly broke the harmony of a sunny afternoon on the margin of the coral sea. As Phillips remarks later, birds probably existed, birds of strange reptilian characters; but we have to wait for the Upper Jurassic strata of Bavaria for the first trace of a feathered animal.

John Phillips's vision has shown us the origins of the roofing-stone. Similar beds, used for the same purpose, have been worked between Collyweston and Easton, south-west of Stamford in Northamptonshire. They

are also of Middle Jurassic age. The " Collyweston Slate " is quarried in winter ; it is exposed, and splits along its bedding through the action of the frost. The workmen then trim it into suitable " slates " during the spring. This industry is known to be as old as the fifteenth century.

Both here and in Oxfordshire, railway-communications have brought in the far lighter slates of Wales, and builders not only find them easier to use, but need far less massive timbering in the construction of their gables. The pleasant uniform grey tint of the old roofs in the Cotswolds, which marks out a village so naturally when we look down on it from the valley-edge, has disappeared from modern buildings, except where some fostering landlord, loving the country, intervenes. He may be an artist, and in these hills, the home of William Smith in 1790, he is probably also a geologist ; but his insistence on the use of strata from the coral sea is no doubt looked on as a vexatious restraint when houses are so earnestly desired. Here, however, in the pastoral upland, there is no pressure of population. The sixteenth century houses, with their mullioned windows, and their picturesque cornices against steep stone roofs, will long remain as natural features of the Cotswolds.

Clustered round the square-towered church, or stretching away from it along the line marked by the valley-road, they harmonize with the strata-edges exposed upon the quarried slope. We look from them to the wind-swept plateau, dropping gently towards London ; its surface was determined by the tilt given to the beds when the last earth-storm in Europe reared the Juras and the Alps. The stratification of the

Jurassic limestones was used for the dip of his roof by the craftsman in the Cotswolds ; Nature has used it for the roof of central England.

The thin calcareous flags of Stonesfield or Collyweston, however delightful to the eye, are not the modern ideal of a roofing-stone. They have long been called slates, a name which dates back to the old French *esclater*, the modern *éclater*, to burst in pieces. This refers to a common property of many stones, and of fissile rocks especially. The well-bedded and consolidated clay rocks known as *shales* are often called slates also. *Clay-slate*, however, the compact purple or grey or greenish rock now familiar *par excellence* as our roofing-stone, is firmer and denser than a shale. To understand it, however, it is well at the outset to understand a shale.

The composition of clay and shale is the same. In both rocks there is a good deal of silica in the form of finely divided sand. The material has been deposited near a coast already rich in clay ; or where an estuary of a sluggish river, incapable of carrying coarse sediment forward, has spread into broad and shallow waters ; or else off a coast of mixed materials, but some miles away from land, where nothing but the finer detritus can be washed outward by the waves, or borne on the last swirls of the rivers as they spread to the purifying sea.

We have seen in our beaches how quartz sand typically accumulates on the coast, though the finest grades of it go forth on long adventures. On our granite moorlands we have watched the feldspars breaking down into residual flakes of kaolin and mica, and these tiny flakes accumulate as the basis of the clays. Compact

feldspathic rocks, such as those that once were in the form of fluid lava at the surface, also yield the materials of clay. The chlorites, which in many ways resemble micas, are final products from the decay of the common minerals hornblende, augite, and dark mica, and they also become washed down as fine material. These substances are buoyed up in the water and float out far from land. They form as a fine-grained mixture the muds that consolidate as clay.

Kaolin, chlorite, unaltered flakes of mica—all these are platy in form and ought, when they sink in water, to fit down compactly on one another. We gather, however, from determinations of the air-space in common clays, that the particles, as they are added to the mass, come to rest in all positions against one another. Pressure, however, brings them into order, reduces the interspaces, and makes them lie with their platy surfaces in parallel planes. The commonest pressure is pressure from above ; the tiny plates come, then, to lie with their broad surfaces in the planes of bedding. Bedding, not noticeable before, is now seen as a delicate lamination in the rock. The structureless clay becomes a shale.

Here and there a change of colour, or a little more sand, calls attention to the stratification. But the mass now parts along the surfaces of the well-marshalled flakes, microscopic though these are. It has less air-space, less porosity, as we say, and is altogether less yielding and less plastic than it was before. A little further pressure would suffice to convert it into *slate.*

Rough and rather lumpy slates, indeed, are produced in this way ; but the typical clay-slate used in roofing has a still more remarkable fissility. Let us visit the

land of the great quarries, like those so well known at Bethesda on the mountain road from Shrewsbury to Holyhead, or those a little to the south at the entrance to the Pass of Llanberis, where the waste from the workings has long broken the beauty of Llyn Padarn's shore. Or, again, the hills above Ffestiniog, whence the sailing-vessels are supplied at the little port, organized by Madocks, to carry the unrivalled roofing-stone of Wales throughout the civilized world.

Here slate is indeed the common stone. Walls are built of thick blocks with jagged edges; upright slabs with holes in them carry wooden poles, or even rods of slate, for fencing; flags of slate make causeways over the grasslands, their surfaces drying quickly after rain; and sharply cut inscriptions on massive tombstones record in slate the longevity and virtues of the Cymric race. Such stones, however, are mere by-products of the art that supports the countryside. In the actual quarries, we shall see why the spoil-banks are so large, and what kind of slate the worker regards as worthy of preservation.

The slate rock juts out boldly on the mountain side. It falls away in slabs, often in great sheets, which break up on the lower slopes. Above us the steeply tilted edges tower, sharp and forbidding, with wisps of cloud gathering between them as if seeking shelter from the wind. Let our first pilgrimage lie that way; we can visit man's diggings later on.

These masses of slate seem to have been pushed up to form the mountain; here and there a more yielding band affords a cleft, in which the water gathers at the crest and provides a permanent and foaming streamlet lower down the groove. On its bank, as we clamber

up, we lay hold of the slates, and a flake of them comes away fresh into our hand.

There are lines across it, slightly wavy, but obviously a little more gritty than the rest. On another specimen these stripes are greenish, in contrast with the deep, grey-purple of the main body of the stone. Surely these bands record the bedding; but they run right across the fissile structure. This slate is something very different from that of Stonesfield; it also differs from those that are merely hard varieties of shale. What we took for stratification-surfaces in the structure of the mountain side, the bands of division that are the leading feature of the landscape, are caused by a splitting of the clay-rock right across its original planes of bedding. The structure is a kind of jointing; but it is due neither to torsion nor contraction. The intimate grouping of the particles in the stone has been changed since it was first laid down.

Perhaps we may be so fortunate as to find a fossil, a poor thing and squeezed all out of shape. Bulges here and there suggest others; but they have lost any characters by which they could be classed as organic remains. Pressure seems indeed to have been exerted on the rock. We are getting near the clue to its fissility.

If we remember the essential constituents of clay and shale, we may ask what will happen when earth-pressures lay hold of a clay mass and act in a direction not perpendicular to the bedding-planes. The little platy particles, between which there is still a good deal of interspace, will shift round until what we may call their platiness is perpendicular to the direction in which the pressure acts. They become extended in new parallel planes. Mineral matter may be added to them;

Fig. 12. Slate, with Cleavage and Traces of Bedding. Co. Wicklow

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mineral changes take place as the temperature rises and as the solutions react upon the rock. Mica in particular develops ; chlorites may lose their water ; there is a general disturbance, tending to new mineral growth. But this growth is impeded in the directions from which the pressure acts, and is aided in directions perpendicular to this by a flowing of the material under compression. The little plates slide over one another, enlarging in many cases as films of newly constituted mica. The rock is ready to split parallel to these surfaces of solid flow ; the old stratification is lost, and counts for nothing in the hand-specimen or on the mountain side. The rock now parts along its *cleavage-planes*.

Where a bed of different constitution breaks the general structure of the shale, it resists the cleavage and is folded (Fig. 12). Its crumpling provides a measure of the compression that has taken place. The same thing is noticeable on a large scale in a country of cleaved slates. Grits and lava-flows are folded ; the clay-rocks between them have lost their lamination, and their planes of cleavage run parallel with the axes of the troughs and arches of the earth-folds.

No wonder that fossil remains are scarce in slates. Clay-balls, such as are formed by rolling on muddy shores, occasionally occur, with distorted elongated forms. The quarryman chooses a stone that is free from these or from the "stripe" due to stratification. He rejects much slate as imperfect, and works on certain profitable "veins." From these, which were originally the purer clays, he splits out thin roofing-stones, perhaps as much as 5 feet long.

When we visit the artisan at his work, we probably find him sitting beneath a shelter built of slate. A slate

roof is over his head ; under his feet, the edges of the slates, worn by long traffic, are seen everywhere on the bare surface of the rock. The roar of blasting, and the crash of falling masses, come to us now and again from the huge excavation in the hills. We realize that for evenness, lightness, and abundance, cleaved clay-slate can have no competitor as a roofing-stone.

Among the blocks that this skilled trimmer of slates has thrown aside are some with brown stains in them, spreading from specks that look like gold. The mineral that causes these is *pyrite,* a form of iron pyrites, iron disulphide, crystallizing commonly in cubes. It cannot be scratched with a knife, nor is it malleable ; we soon distinguish it from gold. It decomposes on contact with atmospheric waters, and one of its common products is brown iron rust. A mere powder of this hydroxide may take the place of the crystal, and a hole appears when the slate is exposed in roofing. Beautiful as the crystals are as shining metallic cubes in the dark grey or purplish rock, they are to be avoided from a commercial point of view. They have, however, a considerable interest when we review the history of clay-slate.

The blue or black muds of modern seas may contain pyrite. It is not added as detrital matter to the clay, but arises from bacterial activities in the water. The sulphuretted hydrogen (hydrogen sulphide) evolved by some of these organisms acts on the dissolved salts of iron and precipitates ferrous sulphide, which finally takes up more sulphur in presence of the hydrogen sulphide and settles into the stable pyrite form. In fossil clays, we sometimes find shells filled up by lustrous growths of pyrite, or of its ally marcasite, which has

the same composition but crystallizes in another set of forms. In slates, the iron disulphide has come together into definite crystals, which are sometimes an inch or more across. The slate of Easdale Island, south-west of Oban, is in parts studded with glancing brassy cubes, the edges of which are perfectly sharp; the surfaces of rock-cleavage are interfered with by the crystals, and are also delicately crumpled and marked by a development of mica that connects the rock with what we shall call in a later chapter mica-schist.

The growth of these pyrite crystals raises again the whole question of "concretions," which came before us when we struck our flints out of the chalk (p. 103). Every crystal is a concretion; when alum or common salt, or potassium dichromate, crystallizes out from solution in water, the water is thrust aside as the crystallizing salt collects from all sides and takes its place. In slate, after cleavage-planes have been set up, in spite of the compacting of the silicates and the further development of mica, the finely divided iron disulphide has collected into larger crystals. The rock-material, as may be seen in thin sections, has not merely been pushed aside; it has been bodily replaced at the points selected for the pyrite growth. As the pyrite came together, it left room for the removed material elsewhere; a transference has actually gone on, and the pure hard pyrite contains no trace of clay. What we call the solid rock is really a solution of one thing in another; in crystal-growth within it, just as in cases of coarse concretion, a shifting of matter and a local concentration has taken place. As R. Liesegang puts it, something has come in, and something also has gone out. The result may spoil our slate for the skilful artisan; but there is

much fascination in tracing back these handsome brassy cubes to the swarms of bacteria breaking up the albumin and the sulphates in the airless depths of ancient seas.

And there is a fascination also in the structure of our common roofing-stone. From the waste of the land and its ultimate slime, Nature gave us the fine clay; she moulded it on the flanks of mountain-ranges and reared it up as fissile slate. The small crumplings of the cleavage-surfaces and the development of mica on them marks a further stage, which leads us on to *foliation*, the essential structure of the schists.

CHAPTER X

THE SEARCH FOR THE FOUNDATION-STONES

IN our chapter on the growth of granite, we dealt with the fact that granites, and hence intrusive igneous rocks in general, are younger than their surroundings. The frequent occurrence of these crystalline masses among the older strata of the globe made it natural for the first observers to regard them all as ancient. Though most are truly ancient, in the sense that they are older than the Triassic period, we are now acquainted with examples that came into place since the mammalia dominated the earth. Before James Hutton, however, made his observations in Scotland (p. 75), there was much doubt as to whether the crystalline rocks now classed as igneous were actually intrusive. Were they not laid down as primitive sediments from a hot sea in the early days of the earth's consolidation ? Were they not the true foundation-stones ?

Associated with them were the great series of " foliated " stones, those known as *schists* and *gneisses.* The term *foliation* was probably current about 1820, but its use was emphasized by Charles Darwin, who was as acute in his geological observations as he was in his

studies of living things. The folia of a rock, the *feuillets* of old French writers, are mineral groupings spread out in a particular direction, or, rather, in particular planes when we consider the three dimensions of the specimen.

Some influence has extended or stretched the constituents of a foliated rock in planes parallel with one another. The platy minerals, the micas and the chlorites, lend themselves readily to this arrangement ; but other constituents, though still making little lumps or knots, exhibit the same tendency ; their normal shapes are lost, and even resisting and almost spherical crystals, like those of garnet, are extended into lens-like forms. The rock so constructed is a *schist.*

A schist, then, is a crystalline stone with its constituents arranged in parallel planes ; these are by no means true planes, but wavy and often contorted surfaces. The mass tends to split along these surfaces, whence the name schist, a rock that can be divided readily into layers, from the Greek *schizo,* I part asunder.

In spite of frequent misstatements, the layers never consist of minerals neatly sorted out from one another. One layer may be rich in quartz, another in mica, another in feldspar or in hornblende ; but in such cases the layers are not composed of a single mineral, but represent different rock-types, the constituents of which are foliated and promote "schistosity."

In treating of the stone called clay-slate, the common slate, we faced the problem of rock cleavage (p. 116). This fissile structure was seen to be emphasized by mineral growth along the cleavage-planes. Let this growth become developed on a coarser scale, and foliation will result. Darwin, in his observations on South America, without the advantage of the microscope and thin

sections, and aided only by his pocket-lens, saw that clay-slate passed continuously into *mica-schist.* "It has appeared to me," he writes in 1846, "that the cleavage-planes were formed of excessively thin, generally slightly convoluted folia, composed of microscopically minute scales of mica. From these several facts, and more especially from the case of the clay-slate in Tierra del Fuego, it must, I think, be concluded, that the same power which has impressed on the slate its fissile structure or cleavage has tended to modify its mineralogical character in parallel planes."

Just as in slate the crystallizing minerals develop along the easiest paths, and the growing edges of their lens-like forms spread in the planes of cleavage, so a coarser development has gone on in the manufacture of schist, until the delicacy of mere cleavage has been lost. Now and then, as in a slate, traces of the original bedded nature of the rock may show that the stratification was quite independent of the subsequently developed surfaces of foliation. On the other hand, the conclusions of Darwin that foliation and bedding are very rarely coincident must be set aside when we study the marginal contacts of large intrusive masses.

Whither shall we go in search of schists? Assuredly to the older portions of the crust. At a time when heating and reheating were more frequent, when molten bodies were nearer to the surface and in large activity, schists were more likely to be formed than in more prosaic epochs. The ever-recurring pressures in the crust, folding, overfolding, and crushing the earth's envelopes, until stones are reduced to dust and run over one another as a subterranean sand, were assisted in those antique times by the greater prevalence of hot conditions.

Many modern geologists believe that the pressures set up in a contracting globe may have sufficed to generate the heat; but in any case the rocks of old days received a more liberal supply. The solutions permeating them were rendered all the more efficient. Chemical particles could move more freely to their fellows; crystalline grains, that had seemed long dead and were even rounded by abrasion, could renew their growth and assume their appropriate forms, subject always to the pressures that allowed more freedom of development in some directions than in others.

Where, then, shall we now recognize the older portions of the crust? They are to be found in the worn-down wrecks of mountain chains, that were reared before the earliest life-forms came upon the earth; or in the core of masses thrust up and overthrust by later movements, which have brought whole regions, long hidden down below, into the realm where denudation can have play. Such areas commonly form moorlands; their surfaces yield soils full of coarse mineral fragments, which gather only in hollows and along river courses in the form of serviceable alluvium. Numerous bosses of grey and lichened rock stand out above the general surface; it is on these that we may often read the romantic history of the schists.

A comparative study of many such areas will convince us that the essential characters of schists have been superimposed on rocks of very varied natures. Schists are, in fact, highly altered from what they were in the beginning, and are so much changed that we give them a big name, and class them as "metamorphosed" or *metamorphic* rocks. What were they, then, in the dawn of time?

To many older writers, they represented something obscure and fundamental. Changed as they might be, it was held that they never were like normal sediments, or normal igneous rocks. Layer by layer, they had been deposited from a primitive ocean. The age of schist-making appeared to be as definitely over as the age when fishes were the highest forms of life. The schists were true foundation-stones, and took, in the minds of these writers, the place occupied by granite in the systems of still earlier philosophers.

Associated with the schists are *gneisses*, rocks in which the layer-structure is still more evident, and in which feldspar usually plays a prominent part. Many of these are merely foliated granites, igneous rocks in which the quartz and feldspar and the dark constituents are all drawn out, as it were, along surfaces of general flow. The dark mica in particular emphasizes this structure; but even where this mineral is absent a streaky character may be apparent.

Larger feldspars in gneiss are rounded on their surfaces and show the lens-like forms that we have already associated with foliation. It is fair to suppose that flow or pressure has had much to do with the characters of masses such as these. Such gneisses are granites or other crystalline igneous rocks in which a foliation has been set up by movement in a viscid or a fragmental state.

But the great majority of gneisses present more complex problems. They repeat on a striking scale what we have noted already in the coarser schists. They consist of layers, sometimes clearly bounded, sometimes intermingling at their surfaces, of very distinct rock-types. The commonest examples display sheets of granite,

coarse or fine-grained, alternating with sheets that by themselves would be classed as mica-schist. The granitic bands are often almost free from mica; the contrast between the two types of layer becomes very striking when the stone breaks across their edges (Fig. 14).

The folding of the layers gives a still more handsome appearance to the rock; but their unequal hardness, and the tendency to splitting (the "schistosity"), renders gneiss unsuitable for use as a polished stone in decoration. At one time these contrasted layers were held to represent contrasted sediments, the constituents of which were either deposited originally in a crystalline form, or were normal sedimentary grains modified by metamorphic agencies. These banded gneisses present one of the most interesting studies in the field, and they draw us at once into the wilder spaces of the earth.

Here, as elsewhere in this little book, I write mainly of what I have seen in happy field-days. Banded gneisses can be traced in the moorlands of Connaught and Donegal, in the sea-washed isles of Scandinavia and the Gulf of Finland, in the open bushland near Bulawayo, and on the "Laurentian plateau" of Canada, where, over square miles of hummocky surface, the forest has been burnt away. The same features are now being recorded by our Indian colleagues in Mysore. (P. Sampat Iyengar, Mysore Geol. Department, Bull. No. 9, 1920). To explain them, we may go back to Charles Darwin's conclusions at Bahia or Cape Town nearly eighty years ago. It is no wonder that gneisses, these widely spread crystalline and primitive masses, should have been long regarded as the true foundation-stones of the crust.

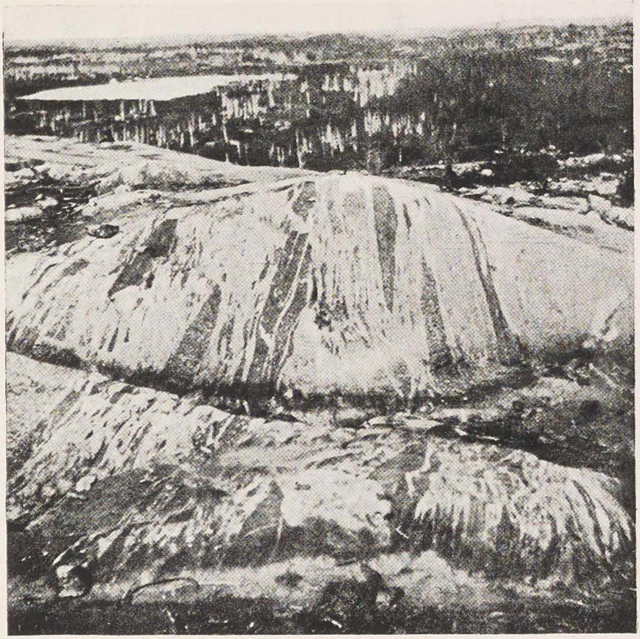

Fig. 13. Gneiss. Sudbury, Ontario.

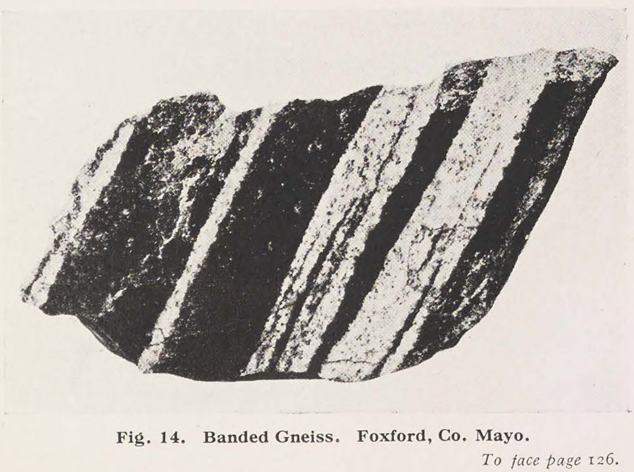

Fig. 14. Banded Gneiss. Foxford, Co. Mayo.

To face page 126.

The specimens of banded gneiss in our cabinet or museum seem to consist of regularly bedded layers. In the open country things appear quite different. The dark layers are seen to be frequently cut across by the lighter ones; they are parts of great flakes that seem to float in a bath of granite (Fig. 13). They often resemble, with their lens-like forms, fishes swimming as a shoal in one direction. Some of these fishes are of enormous size. Here and there a dark sheet runs continuously through the rock for a hundred yards or more. On Mont Blanc these strips may be measured in kilometres, and often, when followed out, they may be traced into a body of normal schists. The dark bands of the gneiss are, in fact, relics of a series that was once continuous. The light bands, giving off veinlets, and surrounding rather than lying between the darker ones, are composed of intrusive granite, which has penetrated along the foliation-surfaces of a group of schists. The banded gneisses carry out the localized features of granite-contacts (p. 65) on a regional and impressive scale.

Again and again the same processes may have been repeated during the risings and fallings of the crust. It is usual to find in the field veins of coarser granite cutting across the whole gneissic structure (Fig. 6). The composite gneiss, which was already consolidated and ready to crack asunder, was invaded by fresh igneous material upwelling from below. Sometimes, as in J. J. Sederholm's favourite examples in the isles of Spikarna, remelting has caused the gneiss to flow apart and almost disappear. The mixed rock, with its constituents of varied history, is sinking back into the uniform condition of an igneous "melt." James Hutton's cycle, igneous

rock, sediment, metamorphic rock, igneous rock, is seen approaching its completion.

The dark bands in the gneiss are very generally of sedimentary origin; not in the sense of many older writers, but normally sedimentary if we trace their history far enough. This can again and again be done in the British Isles in the metamorphosed series that Sir Archibald Geikie has styled Dalradian, a series that forms a large part of the mountain land of western Scotland and north-western Ireland.

These Dalradian rocks are proved in Scotland to be older than the Cambrian period; but they are undoubtedly sedimentary in origin, with the exception of sheets of igneous rocks containing about 50 per cent. of silica, dolerites and basalts, which are often associated with them. They include sandstones cemented by additional quartz and thus converted into quartzites; clays altered into mica-schists, the foliation of which may or may not agree with the original stratification; and recrystallized limestones, containing knots of silicates, and without a trace of any organisms that might reveal their geological age. Perhaps these limestones are not of organic origin, but were precipitated chemically in a sea where such creatures as were present had not yet learned to make calcareous shells or skeletons.

These Dalradian rocks are invaded by granite in many areas. Near the junction with granite they begin to "run." Folding and overfolding set in, as if the mass that had previously preserved its bedding undisturbed had here become softened and so had yielded to the general stress. The contorted limestones of Maam Cross and Oughterard in Connemara, the wild crumplings

of the schist-layers at the north end of the Ox Mountains or at Foxford, and, still more strikingly, the overfolded quartzites under their evenly bedded cover on the great cliff-section of Minaun in Achill Island, all indicate the close proximity of granite. When we examine the actual junctions, we can see the insidious penetration of the igneous rock, bed by bed, as Michel Lévy put it, between the sedimentary layers ; the interlamination of the two entirely dissimilar types of rock ; and then, where earth-pressure has no longer kept the schists from yielding, a burst of granite at some point, tearing the pre-existing mass to pieces, and carrying off lens-like flakes, sheet by sheet, in the triumph of its subterranean advance. We seem truly to be down among the great earth-cauldrons ; yet even here we are by no means in touch with the foundation-stones we set out to seek.

Before the sand-grains that now form the quartzites could have been sifted from the clay-particles that went to form the mica-schists, before the limestones could gather in clear waters in the hollows of an antique land, rocks must have existed from which the constituents of these strata were washed down. These still older masses were nearer the foundations, but only their fragments can be traced to-day. All the world over, the gneisses have failed us in our search. We see only a sedimentary series, worn through long ages from something older still, and metamorphosed through longer ages without losing its essential character of bedding. This series has been further altered by submergence in the zone of melting, and granite has become so incorporated with it that we treat the resulting rock as something distinct, and call it banded gneiss. But the constituent layers of this rock, the granitic and the

schistose parts of it, the igneous and the sedimentary sheets, may be millions of years apart in age.

We come back, however, from our walks across the moorland with a sense of new knowledge, rather than of defeat. The oldest rocks known to us are now known to be sediments, and there is no evidence that the conditions under which they were formed were different from those prevailing at the present day. The origins of the world are not revealed to us in common stones; the story of the evolution of the crust on which we live seems more than ever to be thrust back into realms of reasoned speculation. That there was an evolution among minerals and rocks the philosopher may well believe; but the geologist must still say with Hutton, "In the economy of the world I can find no traces of a beginning, no prospect of an end."

The microscopic details of the metamorphic rocks afford a most delightful study. Can one give any idea of them without the thin slices and the petrographic microscope, which are common now in the hands of many skilful amateurs? The extension of the crystals along planes of foliation, the development of all manner of minerals from matter that was once fragmental, the clearness and freshness of these minerals as compared with the dusty products of decay familiar to us at the earth's surface—all this gives us a sense of new birth and joyous resurrection. The development of light and dark mica, of the aluminium iron silicate crystallized as pink-red garnet, of the aluminium silicate sillimanite, in sheaves of delicate needles penetrating even quartz, may be studied in the schists produced by ordinary contact-action; but on the great regional contacts of gneissic areas growth is carried out on a still more

attractive scale. Occasionally even in schists the conditions for the development of garnet have been maintained with special regularity, and crystals 3 or 4 centimetres across, their faces perfectly developed, stand out like the gems of oriental fancy in a fine-grained micaceous ground. The common earthy matter of the clayey sediment has lost most of its water ; its chemical particles, probably their very atoms, have shifted this way and that to secure the right hold upon their neighbours, and to build up the rigid structure that we call a crystal. Particles not required by this growing concretion have flowed out elsewhere, and particles that are required have flowed in. Clustering round the first nucleus in which the right structure was secured, the atoms have stood in their destined places, like watchers in a field of war. Unless it can be relieved by an atom capable of performing the same task in crystal-structure, no atom of a group in the inner mesh-work can be spared. The crystal must not only grow ; it must hold its own in the face of hostile solvents.

When we see how the mineral constituents have thus developed in the body of the rock, we may ask why was part of the aluminium, so safely locked, one would have thought, in the kaolin of the clay, secured by garnet, another part by mica, another part by andalusite or by sillimanite, or by the exquisite blue mineral, also an aluminium silicate, that crystallizes in a third group of forms and is known as kyanite ? A sequence suggests itself, as in the case of the separation of the constituents of an igneous rock, and this idea is borne out by the inclusion of one of the metamorphic minerals in another. But the crystallization in schist was probably not an orderly process ; it was often interfered

with as temperatures and pressures changed, as solutions came and went; and in extreme cases something was introduced quickly from below, by the addition of molten matter to a rock already foliated, and by subtle intrusion along the planes of foliation.

The metamorphic limestones show a special facility for recrystallization. The carbon dioxide of the calcium carbonate has not been able to escape. Chemists who use the Lawrence Smith method for decomposing silicates in a crucible will know what interactions may go on between heated calcite and other rock-materials. The presence of quartz-veins in an altered limestone often suggests that silica has been brought in by contact-action. Partly from this source, partly from silica present as a constituent of clay, a beautiful series of calcium silicates crystallizes and transforms the rock.

Calcium aluminium garnet often thus develops, in twelve-sided crystals that may be two or three inches across. The larger specimens usually show some uncertainty, as if their constituents had come together in a hurry, leaving interspaces and hollows on their surfaces. Considerable masses of limestone may be converted into grey or pink granular garnet near the contact with invading granite. A natural accompaniment is wollastonite, calcium silicate, in stout little prisms, eight-sided in their cross-sections, and soluble when boiled in acid. It is interesting to note that lumps of concretionary wollastonite may form in lime-kilns, where an impure limestone containing flints has been burnt for lime. Where the limestone contained magnesium, as often happens, contact-metamorphism promotes the development of a number of calcium magnesium or iron magnesium silicates, and the beautiful green

serpentinous marbles are due to this type of alteration. The mineral olivine has grown in them, sometimes with its granular crystals grouped in curving zones; this mineral has taken up water at a later date, and has passed into a softer and a greener form. As J. W. Gregory and H. J. Lavis have shown us, the glorious zoned green marble of Recess in Connemara, which was quarried as far back as 1820, may be paralleled on a smaller scale by the limestones attacked by basaltic lavas in the old crater-ring around Vesuvius.

In the composite gneisses, we have two sets of phenomena of new growth and crystallization—those conducted under earth-heat and earth-pressures, which converted the sediments into schists, and those induced when relief from pressure or sheer melting allowed of the invasion of molten rock, and the foliated series opened its leaves like those of a book from which the binding is removed. The igneous invader swallows up some of the material; but the garnets often resist and stud the composite rock. The included fragments and large bodies of the unbroken schist become penetrated by new matter that crystallizes in their midst; they become "granitized"—their original simpler composition is completely lost. An extremely common product of such action is hornblende, or one of its allies in the mineral group called amphiboles. Rocks rich in amphibole, together with various feldspars, quartz, and garnet, arise from a variety of included masses.

These *amphibolites* form dark inclusions and streaks in composite gneisses throughout the world. When we come across an amphibolite, with its attractive mixture of minerals of contrasted colours, we seem safe in assigning it to some rock, or to some mingled body of

rocks, that has come under the youth-renewing influence of a bath of molten granite.

The most common source of amphibolites, as of amphibole-schists, hornblende-schists, in general, is some igneous rock poor in silica, such as the sheets of dolerite or basalt to which reference has been already made. These seem to resist solution when their former associates have disappeared, and their partial " granitization " allows new minerals to be added to the feldspar and augite proper to themselves. A complete reconstruction takes place, yet they preserve their general gloom, and huge " eyes " of them, round which granite has flowed, stand out darkly in the general field of gneiss.

Many workers have seen, in the features above described, evidence of streaking out under pressure while the rock was in a solid state. I have here discribed my own experiences ; but we must by no means neglect the amount of crushing that these ancient rocks have undergone. Crushing can only take place where there is room for the crystals to break and for their fragments to move apart in some direction. Hence crushing is accompanied by flow, the flow of a solid, which is broken because it has passed the limits within which it can be plastically deformed. Such flow is certainly traceable in schists and gneisses ; but it represents a breaking down and not a mode of construction of such rocks. It is very doubtful if banded rocks, with all their beauty of contorted foliation, can result from a process of grinding in the mills of earth. Far rather, such processes give rise to the fine-grained masses that C. Lapworth has named *mylonites*, rocks that have been " milled down," powdered, compressed in one dimension because their dust has been forced out in others, and ultimately

rendered compact and unattractive, and hardly distinguishable from slate. The microscope must be turned on to these rocks before their essentially fragmental texture, and hence their true meaning, are revealed.

In thin sections, every stage may be traced between gneiss, with its handsome crystals of igneous or metamorphic origin, and the recemented dust called mylonite. Quartzites, schists, altered limestones, become similarly broken down, if they can be allowed room for flow in some direction. The quartz grains are seen to be surrounded by envelopes of comminuted quartz, representing the dust worn from them, and the residual grains are reduced to ellipsoidal forms. Feldspars or garnets that were conspicuously developed in the rock before it was attacked by earth-movement now appear as "eyes," with tails of powder streaming from them. Softer minerals, such as mica, are folded over and flow round the coarser obstacles. With polarized light, the finely granular nature of the ground, its streaky fluidal character, and the strain and deformation of the resisting crystals, are all strikingly revealed. While, then, we may regard banding in metamorphic rocks as a phenomenon of original stratification or of bed-by-bed intrusion, a foliated structure may arise in the case of igneous masses from original flow, or from the deformation of igneous rocks or sediments in the earth-mills after consolidation has occurred.

These banded and foliated stones form a large part of the earth's crust. They are usually ancient, and often they provide the earliest geological record for the districts in which they are revealed. But we come back again in our tracks. With James Hutton, we find that these metamorphic rocks are largely altered sedi-

ments, and that these sediments must have originated in the decay of rocks that went before them. We set out to find the foundation-stones, and assuredly we have not found them.

CHAPTER XI

ON MARBLES

NO doubt there was a time when spherical marbles were made of marble. Precious indeed they must have been in the eyes of players upon doorsteps. Their subsequent imitations in baked clay, with an artificially coloured surface and a dusky white interior, may have been just as good for gaming, but wronged the æsthetic sense of childhood. The glass " marbles," with wonderful spiral intestinal canals, never deserved to bear the honoured name. Moreover, they were apt to be mistaken for sweetmeats by indiscreet and infant onlookers.

The original game was played with the spoils of Derbyshire, Tuscany, and Ægean isles. The *Encyclopædia Britannica* gravely tells us that " alley taws " derived their name from alabaster. At one time the fathers of the players (but had they not been players also ?) adorned their waistcoats with marble buttons, which were changed from one suit to another. To the cultured eye, these stones were reminiscent of post-chaise expeditions and the tour of Europe. It was at that time the duty of a country gentleman to display an inlaid table, or a collection of cut and polished

squares of marble, as a sign that he had passed, unscathed in virtue, across France to the Vergilian lands. When he sat down after a speech in Parliament as the elected representative of a clergyman and five small farmers, his very snuffbox recorded in stone the taste of the Italian craftsmen.

In this way, and often for pure appreciation of mineralogical science and of art, numerous exhibits of foreign marbles accumulated in the British Isles. Their purchasers had a genuine interest in the beauty and variety of the stones, and a slab of dazzling whiteness would recall the wagons drawn by long-horned oxen in the dusty roadways of Carrara, while another of grey, delicately veined with pink, would revive memories of sunlight and blue water, and a chat with Sir Samuel Hood on Plymouth Hoe. It is a matter of regret that these collections were seldom completely labelled, and that so many have now been scattered through changes of taste and occupation.

The decorative artists of ancient Egypt used a compact white limestone, almost a marble, for lining the walls of temples and of tombs, and on this they carved scenes of religious tradition, of contemporary history, and of ordinary domestic life. The choice of limestone for sculptured work was originally due to its comparative softness and to its frequent regularity of grain. In spite of the assurances of road-contractors, who still put forward this easily broken rock as a substitute for dolerite or quartzite, there is no such thing as a hard limestone. However, when it crystallizes in small granules throughout (as described on p. 85) it is on a fair way to be a marble. Limestone is hard enough to take a reasonable polish, and a smooth surface

does not encourage water to rest on it and damage it by solution. All the same, even polished marble soon becomes dull in the atmosphere of modern towns. Our smoke would have done more harm to the glories of the Parthenon than Turkish neglect or the guns and greed of Morosini. Marble is essentially a stone for internal decoration, and in the opulent imperial days the Oriental taste for coloured hangings was translated into marble walls in Rome.

Some marbles are merely grey limestones to which fossil remains, coiled shells, sea-lily stems, and so forth, impart a patterned character. Our British Carboniferous Limestone supplies many good examples. A favourite stone with the cathedral-builders of the thirteenth century and onwards was the Purbeck Marble, a bed composed of dark grey calcareous mud infilling the closely packed shells of Paludina. This freshwater snail, a genus still living, abounded in lakes at the time when southern England was emerging from the marine Jurassic overflow to the estuarine and lacustrine conditions evidenced by the Wealden strata. The bed made by its remains, though yielding no large blocks, caught the eye of the Anglo-Norman sculptors on account of the pattern given to it by the curved edges of the shells. Its dark tint when polished was pleasantly contrasted with the yellowish white of the Jurassic oolites and other massive limestones used in architecture, and subsidiary columns were run up, carrying no weight in themselves and necessarily cut into comparatively short sections, beside the tall supporters of cathedral naves and towers. Occasionally a recumbent figure for a tomb was carved in Purbeck marble; but time has treated such large blocks badly, and the snail-shells

proclaim their unbroken permanence by falling out under the hands of pious charwomen.

The similar grey Sussex Marble occurs higher in the stratified series, and is of Lower Cretaceous age. After the Hastings Sands had been laid down, which are so well known on the coast of Kent and on the fir-clad ridge of Crowborough Beacon, Paludinas of a larger and a smaller species flourished in the Wealden lake, and provided a stone that has been quarried at many places in the pleasant wooded country between the two escarpments of the downs.

In Italy, shelly limestones have been known as *lumachelle*, and an example of exceptional magnificence, from across the Alps in Carinthia, often goes under this general name. In this stone the iridescence that is known so well in the Pearly Nautilus, and in the oyster-like Placuna of Oriental seas, is developed in the included molluscan shells so as to surpass the fire of an opal. Flashes of flame seem to play within the rock when a cut surface is turned about in the hand. Though its locality is on the German side, it surely needs the scintillating vowel-sounds of the Italian language to express its "viva lucentezza madreperlacea, con riflessi iridati a tinte vivaci di grande effetto" (C. Artini, *Le Rocce*, p. 515, 1919).

Shelly marbles, however, do not satisfy the demands of statuary or of slabs for colour-decoration. To produce a pure white marble, like those of the Isle of Paros, or of the hill of Pentelikos north-east of Athens, the original limestone must have been something like a chalk. All traces of bedded structure or of shells must have vanished during recrystallization, and veins of coarser calcite should be absent. Even at the famous quarries of

Carrara in the Apuan Alps, quartz or schist occasionally mars a block. Considering the origin of most limestones in the common receptacle of the sea, it is not wonderful that pure statuary marbles are rare and highly prized. Their relative abundance in north-western Italy has tempted the mortuary sculptors of Genoa into a riot of grotesque extravagance ; and it is doubtful if Athens could have recorded her far nobler taste in marble had not the possibilities of the stone been realized for centuries close at hand.

The Greeks felt that their white stone was monotonous and chilly, even in the Ægean sunlight, and there is no doubt that they painted in bright tints and in gold the surface of architectural work and of certain statues. Veined and coloured marbles are certainly preferable to statuary types for decoration. A bath of Parian may set off pure water and a dainty skin ; but a slab of Parian is cold comfort on a wall. Hence the imperfections introduced by Nature, imperfections made glorious by what may be called the metamorphic resurrection, have turned many common calcareous sediments into valued ornamental stones.

Ferruginous stains, for example, have often spread along cracks, and have sometimes permeated the whole limestone. The calcite has become pink or pink-brown, forming bold streaks across a greyer ground, in which traces of fossils may still remain. The marbles of Plymouth and of Midleton in the county of Cork are of this pink-veined type ; the former is of Devonian and the latter of Carboniferous age. A wet day in Plymouth brings out the splendour of what is here a very common stone, used almost in the rough for walls and even pavements.

At Little Island in Cork Harbour the stone is more uniformly iron-stained, and little of the original buff or grey colour remains. Earth-movement has crushed it and induced a sort of flow; the patterning of the marble is due partly to this grain, and partly to the remains of shells and corals. This rich red stone has been much used as a facing for internal walls. The brown-red Jurassic marble of the Alpine foothills near Verona, which is seen in so many buildings, from the seats of the Roman amphitheatre to the porches of the "brick and marble" Lombard churches, is much of the same type as that of Cork. Its most striking feature is the frequency of coiled ammonites, which play almost as important a part in its texture as freshwater snails do in the fine-grained Sussex marble.

A red oolitic limestone near Bristol, of Carboniferous age, is common as a marble in collections. The small concretionary grains, with their concentric structure, have become iron-stained as well as the fossils of the ground, and the stone is often cut for ornaments. Black marbles are sometimes coloured by a mere impurity of mud; but a very small quantity of anthracite or graphite, arising no doubt from the decay of organisms, suffices to give a deep colour to a limestone, which is intensified when the stone is polished. The curving white shells of Productus in the black limestone of Kilkenny produce a natural pattern of a somewhat vivid character.

Green marbles are usually coloured by serpentine or chlorite; the splendid banded variety from Connemara has been referred to as a product of igneous alteration in the chapter on the earth's foundation-stones. In this case material has been added to the limestone from

without, though the magnesium and iron on which the growth of olivine, and subsequently of serpentine, depended may have been originally present as carbonates in the rock as deposited in the sea.

The colour that constitutes the glory of so many decorative marbles is in most cases due to mineral readjustments within the stone. It marks a step towards the larger modifications dignified by the name of metamorphic change. While casual impurities in the original sediment may result in ornamental veins, a transference of calcium carbonate from one part of the rock to another causes any crevices to be filled up with pure white calcite, freed from duller mineral associations. The most startling developments occur when coloured limestones come under the influence of earth-pressures and earth-movements. The soft rock breaks and runs, as it were, between the millstones of the sterner masses. If it is not ground down altogether into a finely granular calcareous schist, it displays a splendid broken or "brecciated" structure, the angular blocks being recemented by calcite when the region eventually recovers its stability.

These handsome *calcareous breccias* are largely quarried on the south flanks of the Alps. Every stage can be traced from those in which the blocks have been pulled apart without any serious shifting, so that the original arrangement of the beds can still be followed out, to those in which a bold admixture has occurred, the torn strata being pushed over and across one another, until the whole looks like the consolidation of a talus on a mountain side. The cementing calcite is almost always whiter than the limestone blocks, and thus forms conspicuous and ramifying veins. The blocks may be

yellow, green, or purple-red ; occasionally fragments of white marble are set in a streaky red cement. Some of these breccias are so coarse and so variegated as to be unsuited for artistic decoration. They draw the eye from architectural lines to thoughts of the Last Day and the crash of worlds, as depicted by the late John Martin in the engravings so often placed for comfort in the best bedrooms of hotels.

Our forefathers justly went to Italy for their collections. To put it more truly, Italy thrust her love of coloured stones upon them. Venice and Ravenna to this day, to mention only two examples, are museums in which all the marbles known in the Mediterranean region have been put to a decorative use. A slab has often been sawn down the middle and opened out, so that the same patterning appears on one half as the mirror-image of that on the other. The two are then set up side by side upon the wall, as an appeal to the love of symmetry that characterized, even at an early date, much of our European art. It must be left to private judgment to say if the effect is more justifiable than that produced by the two china dogs on the mantelshelf of an English inn. This duplication and many other interesting matters are dealt with by Atchison, Young and Brindley in an illustrated paper on "The Use and Abuse of Marble for Decorative Purposes," *Journ. R. Inst. British Architects*, Series 3, vol. ii., p. 401, 1895. See also Atchison on "Marbles," *ibid.*, vol. x., p. 524, 1903.

Occasionally the streaking-out of a veined and brecciated marble has produced a flow-structure akin to that of schist. *Calc-schists* indeed exist, of which the red Cork marble represents the opening stage, and the

minutely crystalline white examples from the Alps, gleaming with scales of mica, are the truly metamorphic types.

A banded marble of completely different origin, the famous " onyx-marble " of North Africa and Mexico, is formed by layers of colourless and yellow-brown stalagmite, calcium carbonate deposited from solution in subterranean cavities, the handsome effect being due to the different stainings imported to successive layers at their birth.

There seems no end to the variety of marbles ; there can be no end to man's enjoyment of them. The city-restaurants, the palace-hotels, the Stock Exchange of London, and the club-rooms of men united by love of learning or of motor-cars, are successors of the baths and temples of imperial days in Rome. Taste in marble fortunately was not limited by religion. The founders of Christian basilicas in the fifth century stole from the deserted halls of rhetoric, and from villas ruined by the Huns, the choicest stones that they could find. The quarried slabs and columns lay here ready to their hands. The column did not always fit the capital assigned to it ; but piety atoned for a certain haste in reconstruction.

And now once more the wealthy corporations are gathering marbles from the ends of the earth to conceal the blank ineptitudes of towns. *Tout casse* is a proverb ; and there may yet be written in marble another of the world's great tragedies. Between the slope of Byrsa and the Gulf of Tunis there runs a stretch of tilled and level land. By the crescent of the deserted harbour, the villa of a Moslem merchant rises, white and clean against blue water ; on the near side, two or three Arab

huts stand on the edge of recent excavations. A few upright columns, probably from Numidia, have been cleared from the earth that for centuries gathered round them. Uninvited, unwelcomed by host or hostess, we enter roofless houses and cross their tessellated floors. But the horror and the waste of it come home to us when we gain once more the upper terrace and walk along the furrowed fields. Here at our feet is the wreck of two great cities; here is Carthage, that was dead and rose again. Broken pottery and cut marble are the common stones of the brown soil.

CHAPTER XII

THE DHUSTONE OF TITTERSTONE CLEE

NOTHING with a name so hybrid and so romantic can be quite a common stone. But the dhustone, the blackstone, of the Shropshire Marches is now known far beyond its quarries on the Clee Hill crest. It is carried by rail a hundred miles or more from its source, for it constitutes one of the finest road-metals between the British Channel and the Cheviots.

Above the old town of Ludlow, built in beauty, girt with beauty, as befits the warden of the Marches, the scarp of the dhustone rises on the eastern skyline, where a high British camp once dominated the valley of the Teme. The resisting powers of the stone have protected a patch of Coal Measure and underlying Carboniferous strata 1,700 feet above the sea and 1,500 feet above the vale, and beneath them, and on the Brown Clee Hills to northward, the edge of the Old Red Sandstone goes down steeply into Corfe Dale.

The dark grey dhustone forms an intrusive mass, a sheet slightly tilted, which provides an effective scarp. It has penetrated into the stratified series from an earth-cauldron far below; it is a type of the igneous rock now widely known as *dolerite*. A dolerite is merely a

coarse *basalt*; the chemical and mineral constitution of the two rocks is the same. With a pocket-lens we may see in dolerite "rods" of light-coloured *feldspar*, which are in some cases rod-like because they are cross-sections of thin plates. There is a dark aluminium iron magnesium calcium silicate called *augite*, and there are usually metallic-looking black grains, which are *magnetite* (magnetic iron oxide), or *ilmeonite*, a compound of iron and titanium oxides. In many cases, dolerite shows also yellow gummy-looking granules, which we soon learn to know as *olivine*. This mineral, however, decomposes readily, even underground, when water permeates the rock, and it passes into a dull green fibrous and compact silicate, easily scratched by the knife, called *serpentine*.

The rock is as crystalline throughout as the granite of Shap Fell, but is not so coarse in grain. Its dark tint indicates a large proportion of dark minerals; the powdered dolerite when analysed yields far less silica than would be found in granite. There is not enough to produce quartz when the other minerals have been built up. The feldspars, the range of which we discussed when dealing with their potassium representatives at Shap, are of calcium-sodium species. They contain less silica than is found in orthoclase and microcline; they are heavier volume for volume; and they give rise to other calcium silicates, and even to the carbonate calcite, rather than to kaolin, by their decay.

An analysis of the dhustone of Titterstone Clee, by J. H. Player, is quoted in F. H. Hatch's *Textbook of Petrology*, in which special attention is given to our British igneous rocks. Side by side with it we

take from the same work an analysis by W. Mackie of the granite of Cairngorm, which is richer in potassium than that of Shap, and affords in this respect a more marked contrast with the dolerite.

	Olivine-Dolerite. Clee Hill, Shropshire.	Granite. Cairngorm, Aberdeenshire.
Silica . . .	48·4	76·01
Alumina . .	13·4	13·47
Ferric oxide . .	4·0	1·54
Ferrous oxide .	8·5	—
Magnesia . .	6·5	0·06
Lime . . .	8·6	0·54
Soda . . .	3·1	2·32
Potash . .	2·1	5·57
Water . . .	2·2	0·56
Titanium dioxide .	3·1	—
Other constituents	—	0·12
	99·9	100·19

It is clear that if both rocks were melted and cooled under the same conditions, their mineral constitution could not possibly be the same. The Clee Hill dolerite is a type of what are commonly called *basic igneous rocks*. Such rocks are more easily fusible than those that contain less iron and more silica, and they are distinctly heavier. If we cut a cube of dolerite and a cube of granite of the same size, the former will be heavier than the latter in the proportion of 3 to 2·6. If the dolerite cube weighs 3 kilogrammes (3,000 grammes), that of granite will weigh only 2,600 grammes.

It has been specially urged in recent years by R. S. Daly of Harvard, and is now generally held, that these denser igneous masses occupy low regions in the earth's crust. When they come to the surface, they may rise directly from greater depths than those where the ma-

terials of rhyolite (p. 221) usually lie. In former days, long before life came on the earth, a general separation of " basic " material from that richer in silica probably took place, and the same thing may be repeated nowadays in the contents of local cauldrons. There certainly seems to be plenty of basalt in the crust ready to be squeezed up when an outlet opens ; it is the best-known type of lava that flows out at the surface of the earth.

The dhustone of Shropshire cooled under other rocks, and so became crystalline throughout ; but W. W. Watts (" Shropshire," in *Geology in the Field,* Geologists' Association, 1910) points out that it and other dolerites in the neighbourhood are identical in character with those associated with the great Cainozoic outpourings of basalt in the north-east of Ireland and the Inner Hebrides. Perhaps the dhustone also, in its molten state, broke out somewhere at the surface, feeding a volcano that is now entirely worn away. Denudation has left us the mere roots to guess by, just as it has where dyke after dyke of dolerite strikes across the older rocks in southern Scotland.

In its undecomposed condition, dolerite makes an ideal metal for the roads. It does not powder down like granite, and it is, on the other hand, tough rather than hard and flinty. It breaks into angular blocks, which " bind " well when rolled in. Its compacter relative basalt makes a fair substitute, but must be chosen with still more care ; from a shallow quarry it may prove of little value. Brown rubbly basalt, in which the augite has passed into calcite and chlorite, the olivine into serpentine, and the iron compounds generally into iron rust, merely adds so much mud to a surface in need of firm repair.

The effect of the resisting sheet of dolerite on the landscape caught our eye when first we saw the Titterstone Clee. In many places sheets of the fluid rock have been injected along the bedding-planes of strata, and, if the series is tilted, their edges weather out as conspicuous steps across the country. Such intrusive sheets have well been styled *sills*. A noble example is seen in the Great Whin Sill of northern England, which is believed to be continuous underground from the Northumbrian coast near Holy Island to that of the Solway near Carlisle.

W. Topley and G. A. Lebour (*Quart. Journ. Geol. Soc.*, London, vol. xxxiii., p. 406, 1877) followed out in detail the course of this sill in the marine Lower Carboniferous strata, and showed how it lay now somewhat higher, now somewhat lower, in the series. This could not be the case if it had been poured out on the sea-floor as a lava-flow and became covered by later accumulations. The difference between two of the levels at which the sill lies in the strata of eastern Northumberland is as much as 1,700 feet. While for the most part it seems to run evenly in the bedding-planes, as it does at the beautiful waterfall of High Force on the Tees, it none the less in certain parts of its course cuts across the strata; moreover, it sends out veins and knobs into the beds that lie above it. An excellent instance of this is illustrated in the paper referred to from Elf Hills quarry, in the open country about midway between Bellingham and Morpeth.

If we had any doubts as to the intrusion of the Whin Sill dolerite into its Northumbrian surroundings in a hot and molten state, let us note that it has at various points burnt the coal-seams near it. Numerous pieces

of evidence are quoted by Topley and Lebour from their own observations and those of their predecessors, showing that both the beds above and below the sill have been altered by " igneous " contact.

Where the Tees, fed by trickling tributaries from the high fells and " commons " on the Durham-Cumberland border, has boldly notched the Carboniferous upland at High Nick, the Whin Sill resists, flaking off along its vertical jointing, and forms the waterfall of High Force, some 60 feet in height. But the finest features of the sill lie northward of the Tyne. On the quickly rising moorland north of Haltwhistle and Hexham, its upturned edge, where the strata dip south-eastward, faces the still wilder country of the Scottish border, and forms a scarp that appealed to the strategists of Hadrian. Here, undulating from crest to crest, the Romans carried the line of the Wall, which for three centuries divided the country won for civilization from the intractable Pictish territory of the north. Though the squared sandstone blocks, hewn in the local quarries where the legions carved their names, have been freely carried off to build mediæval villages and to fence the modern farms, the lower tiers of the Wall still remain as a monument of imperial rule. And when the untamed borderers stormed the Wall early in the fifth century, and swarmed across the castles on the Whin Sill edge, it was no glorious uprising of an oppressed " small nationality," but a national disaster for all Britain south of Tyneside. The crash of the British cities was completed by the Saxon raiders, entering from the unguarded eastern sea ; yet the dolerite sill had none the less played its part in the moulding of our mingled folk. The Roman habit of discipline,

born of Roman principle in war and peace, has surely left its traces in the England of to-day.

At the north-eastern end of the exposures of the Great Whin Sill, the rock comes boldly out against the sea, and on it the Saxons reared a fortress, known as Bamburgh Castle, against their kinsmen and enemies the Danes. In Norman times this castle was developed, like the famous "holds" of Dunstanburgh, Alnwick, and Warkworth, against the frequent intrusions of migratory and retaliating Scots.

The crag on which Bamburgh Castle stands shows well the columnar structure that is so often associated with basaltic rock. Any compact igneous rock may shrink in this way; any compact contracting material may produce fairly uniform columns rising from its drying surface. Commercial starch and the mud of estuaries have often been cited as examples; and in basaltic lava the Giant's Causeway of the Antrim coast and the relic of another flow at Staffa have furnished types known far beyond the text-books of geologists.

Both these lava-flows were poured out after the Chalk sea left our islands, and probably when the crust was restless and heaving prior to the great movements that reared our modern mountain-chains. They have been cut into by the sea, so that their inner structure is well displayed. Similarly the splendid instance at Jaujac in Ardèche, studied by G. P. Scrope in 1821, has been dissected by the Alignon river, leaving a columnar "mural precipice" 150 feet in height, on which the village stands.

The "palisades" above the Hudson River, so familiar to travellers going northward from New York, are

the columnar face of a great sheet intruded into shales and sandstones. This igneous mass is about 350 feet thick at Jersey City, and 850 feet farther north in Rockland County.

While such vast quantities of igneous matter force themselves between the leaves, as it were, of a volume of stratified rocks, others take advantage of more or less vertical joints, which open for them in a broad extent of warping country. Basalt often reaches the surface by these linear passages, emerging in wide floods or perhaps from a line of little cones. When cooled in the clefts, the dark rock then forms *dykes*, which stand up like walls as their weaker surroundings crumble down in epochs of denudation. Since cooling takes place from the two parallel surfaces into the adjacent rock, the dyke is often columnar, the columns lying in such cases, as in lava-flows or sheets, perpendicular to the surfaces of cooling and therefore in general horizontally.

Basalt erupted at the surface tends to be less completely crystalline than our doleritic dhustone. The bubbles left in the rock by escaping vapours, which are mostly steam, record the frothing of its upper portions. Here and there it has cooled so quickly that a small amount of black glass remains, in which crystals have not had time to form. But this glass is usually crowded with specks of magnetite, since the iron oxide, uncombined with silica, steps out very early in the history of the consolidating rock. The lavas of Vesuvius, so well known as types in our collections, are basaltic, with enough potassium to give rise to the white silicate leucite, in addition to calcium-sodium feldspars.

Floods of basalt deluged the region of west-central

India in late Cretaceous times, and are traceable inland from the sea-edge of Káthiáwar and Bombay over a plateau-country covering 200,000 square miles. At present, the most active example of such fluid and widely spreading lavas is found in the Hawaiian Islands, where the crater of Kilauea contains a seething lake, Halemaumau, the waves of which undermine its walls, while the spray of lava, cooling as brown threads of glass, is caught by the wind and carried through the air. An observatory has been established on the crater edge, and a bulletin is regularly issued recording topographic changes, daily movements, and the nature of the gases in the molten rock.

Every now and then basalt breaks out in Hawaii from fissures, and flows swiftly to the sea across the vegetation of the slopes. Successive sheets in this way in time level up a country, and account for the great lava-plateaus that are now known from all quarters of the globe.

The dhustone, then, as we pick it up from a roadside heap in central England, brings us into touch with the grim recesses of the earth. Some day, the bending and stretching of our country may produce once more a series of parallel cracks, like those that are traceable by the dykes of northern Britain, running with marvellous regularity N.W. and S.E., and recording our last volcanic disturbances of early Cainozoic times. Long before the lava once more floods the surface, earth-movement will probably have become manifest in earthquakes, and our mechanical industries will have sought a safer home. The agriculturist, taking to wooden houses, and to ox-wagons in place of railways for the export of his produce, may for a long time hold his own. A genus of

monkeys, Semnopithecus, has survived in northern India the rise of the Himalayan chain. Man, simplifying his tastes, may prove himself an equal master of adaptation ; and perhaps, after all, the vision in which we are indulging may not be realized during human occupation of the earth. It cannot interfere with our enjoyment of the landscape from the crest of Titterstone Clee ; but it may add an imaginative touch to after-dinner conversations on the dhustone.

CHAPTER XIII

A LODESTONE

EARLY experiments on magnetism were made with a stone called Magnes. It is probable that this came from Magnesia, the name in ancient times of the mountainous barrier between Thessaly and the sea, where Ossa and Pelion, rising like the Paps of Jura, suggested heights where man might mingle with the gods. Marvels might well occur in such a country.

Hence *magnes* (with its genitive *magnetos*), a name given to dwellers in Magnesia, became applied to a black stone collected there as a curiosity, a stone that attracted its own particles and also metallic iron. Mineralogists have called this magnetite, and the words " magnet " and " magnetism " are derived also from Magnesia.

" Magnesia," the oxide of the name of the metal magnesium, and " manganese " come also from the same source, the latter by loose spelling and a confusion of its dark ores with magnetite. There was once a worse confusion, since Cesalpino tells us (*De Metallicis*, cap. 55, 1602) that the black mineral " manganese " which was used for clearing glass from coloration by iron, was called by Albertus Magnus, about 1250 A.D., " magnesia." It is interesting to note that " manga-

nese" is the spelling of Cesalpino's Latin text. The added manganese was believed to draw the iron out of the glass much as magnetite drew iron to itself. We now know that it alters the state of oxidation.

We must not pass over a statement quoted from Nicander of Colophon, who wrote on agricultural science about 120 B.C., and who says that a shepherd named Magnes, wandering on Mount Ida, found that the nails of his shoes and his iron-shod staff were held down by a certain rock. Nicander may have been willing to glorify his own district. Our point is that the ancients knew, and named "magnes," a stone that attracted iron. Some one, unfortunately unknown, discovered that it could impart its property to hard metallic iron, and thus invented magnets.

Some one else suspended a magnetized rod or needle, very possibly a real needle that proved handy, by its centre, and found that, for his locality, it always came into the same position of rest. Imagine the joy of testing this observation; the suspended needle, or, perhaps, a needle floated on a cork in water, would be carried from the study to the courtyard, from the cellar to the roof-garden, and in all these places it was found to point fairly north and south. Perhaps this was not discovered until the twelfth or thirteenth century of our era; but mariners were not slow in seeing its application to travel on the open sea. For many centuries the iron or steel of the compass-needles, used from Zipangu to Hormuz and New Spain, was "infected," as Cesalpino says, by stroking it with a block of the Magnesian stone.

This ore was hence styled Loadstone or Lodestone, the stone that gives a lead. I think we may prefer the quainter spelling "lodestone"; even Drummond of

Hawthornden moves heavily when he writes of a lady as the "loadstone of all hearts."

The composition of magnetite is an iron oxide, Fe_3O_4. When molecules seemed to be distinct bodies in crystals, it was regarded as a mixture of an equal number of molecules of ferrous oxide, FeO, and ferric oxide, Fe_2O_3. The latter is well known in nature as the handsome iron ore hæmatite, which receives its name from the dull blood-red colour of its powder. Magnetite is essentially black; like hæmatite, it is unscratched by a knife, and it contains 72·4 per cent. of metallic iron.

The massive blocks are made of a number of granular crystals; but all the same they often show polarity. That is, one point in the mass attracts a pole of a magnetized needle, while some opposite point, held towards the same pole, repels it. The block, therefore, acts as if there were a bar-magnet in it. The powder of magnetite is strongly attracted by the mineral, and stands up on it in bristling tufts. I remember how the refusal of the dust to fly away made collecting difficult in a lode in Transvaal, and Cesalpino remarks that a fur seems to accumulate on specimens when struck. In very varying degrees, examples of the ore can be made to lift up iron objects, and a string of nails or steel pens can be hung on, one below another, the first being magnetized by induction on contact with the mineral, and each of the others by induction from the one above.

Well developed crystals of magnetite are frequent in igneous rocks poor in silica, such as basalts, where they look like dull grains of iron with the lens; their crystal outlines can be seen in thin sections under the microscope. Just as pyrite develops in slates, so magnetite

may develop in chlorite-schists, crystals a centimetre across being fairly common. The chlorite-schist may be a much decayed and metamorphosed igneous rock, and the magnetite may represent the concretion of iron oxide that was at one time more generally diffused.

The crystals from the schists give us rather satisfactory material. They have eight faces, which often differ considerably in size. Regularity of growth in crystals depends on perfect regularity in the food-supply from various quarters. The crystals with irregular development in faces that ought to correspond, and that would be shown as equal in form and area on a drawing or a model, are sometimes said to be distorted. Distorted or deformed crystals do occur among minerals with curved faces or even a spiral mode of growth ; but the mere overgrowth or undergrowth of a face does not imply distortion. This is beautifully shown by measuring the angles made with one another by any two adjacent faces of an eight-sided crystal of magnetite. One way is to cut a notch in a card, to hold the card perpendicular to the edge made by the two faces, and to enlarge the notch until its sides fit down exactly on the crystal-faces. A succession of trials shows that the angle of the notch, determined from an average, is 109°28′.

The error in this rough way of reading will be sometimes one way, sometimes another; but it is not of Nature's making. The crystal with this uniformity of angle is well known to geometricians as the regular octahedron, an eight-sided double pyramid, every face of which is of equal area and an equilateral triangle.

This is the form, then, that Nature tries to build when magnetite crystals grow. It is one of the most regular

forms, and places the mineral in the most symmetrical class known to crystallographers. An octahedron can be cut across in nine different directions, so that the two severed parts are exactly equal and each is an exact reflection of the other. The cube is an example of the same high symmetry, and it is a pretty exercise to see how it may be thus divided in nine ways into balancing halves.

Not infrequently, a magnetite crystal produces an almost perfect octahedron. In all cases, however, *the angles are perfect*, and tell us what is intended by the form.

Magnetite as a stone, capable of being quarried, occurs in various lands, and it is an attractive and valuable ore of iron. In our own islands there is a steeply dipping lode on the hillside at Ballycapple, near Kilbride, south-west of Wicklow town, in which a mine has been worked from time to time. The mineral here seems to replace the igneous rock of the district, rather than to have separated out from it. In many places, however, direct association with crystalline igneous masses leads to the belief that the magnetic ore is a separation-product, a concretion, from the rock while it was in a state of fusion, just as metals will separate in slags used in smelting. The dense material, withdrawing itself early in the history of the cooling rock, may become concentrated in lower parts of the cauldron by gravitation. The Scandinavian ores seem to be of this kind, though there is the possibility that the huge band of magnetite at Kiruna results from the metamorphism of iron-bearing sediments enveloped by intrusive igneous rocks. We shall return to this matter later on.

Bedded magnetite ores also occur, always, it seems,

among antique strata, as if time were a factor in their production, or as if some condition of deposition had helped matters in former days and then passed from the economy of the earth. Yet it can be clearly seen that these banded ores were not deposited as magnetite. Gradations can be traced from the magnetite through hæmatite to ordinary brown iron oxide and even to iron carbonate. The two latter ores are familiar in swamp deposits at the present day. A loss of carbon dioxide and the taking up of water convert the carbonate-ore into iron rust ; loss of the water, perhaps under the general heating experienced by old sediments, reduces the iron rust to hæmatite. A further step towards reduction, especially when the series is threatened by igneous invasion, converts hæmatite into magnetite ; and there the series stops. Reduction to metallic iron does not take place in the ordinary processes of the upper crust, though this metal, alloyed with nickel, occasionally reaches us as blobs and granules in basaltic rocks that have come from far below.

The difficulty of obtaining metallic iron where air has access to the mineral is seen in experiments with the blowpipe. When a splinter of hæmatite, for instance, is heated even in the reducing flame of the blowpipe, it refuses to part with all its oxygen, and is merely converted into magnetite. It is interesting, however, to note the change in physical properties. Not only is the powder now black instead of red, but the fragments can be attracted by a magnet, and they bristle up on the end of it like pieces of metallic iron. Glowing carbon is necessary for complete reduction.

Though most occurrences of stratified magnetite seem to be due to reduction of more normal bedded ores, yet

magnetite sands naturally accumulate from the decay of "basic" igneous rocks. Black sands, rich in granules of magnetite and the titanium-iron oxide ilmente, are known among the shore-deposits of our own islands; the high specific gravity of the ores have aided the natural processes of separation. The magnetite layers in the quartzites near Pretoria in South Africa may, perhaps, have been formed in this way; but in most cases one may suspect a reduction from material that was once more highly oxidized.

I had the good fortune to visit Kiruna in Lapland in 1910. It seemed possible that the famous band of ore might be, as above hinted, a product of metamorphic action. A series of iron-bearing sediments forms the floor of the Kiruna district. These highly altered and ancient sediments have been uptilted, and have been invaded by igneous rocks (fine-grained granite and syenite) with some 75 to 55 per cent., and mostly 60 per cent., of silica. Such rocks are very unlike the dark heavy masses that we associate ordinarily with magnetite or other iron ores. The pale pink and grey igneous rocks of Kiruna are contrasted strongly, for instance, with the dhustone of Titterstone Clee (Chapter XII). Those who have made detailed studies of the district believe, however, that the magnetite rock has separated out from the igneous "melt" during its cooling, leaving it all the more siliceous, and leaving behind also blobs of ore in the syenite that were unable to sink down in time and join the larger mass of magnetite (see, for example, R. A. Daly, "Origin of the Iron Ore at Kiruna," *Vetenskapliga och praktiska undersökningar i Lappland*, Luossavaara-Kiirunavaara Aktiebolag, 1915. Daly gives references to the works of other authors).

Let us now try to see something of the evidence in the field.

It is evening when we leave Stockholm in the express that is ultimately to carry us to Narvik on the arctic edge of Norway. Next day we cross river after river, foaming from the Scandinavian divide, and cutting grooves in a country of crystalline rock and forest, where lumbering is almost the only industry. Between us and the sea there are some green stretches of agricultural soil, where the Baltic lake once laid down its loams, spreading westward as the ice drew back. All the next night, borne inexorably northward, we traverse wild expanses. We no doubt looked out of our berths at the tiny station of Polzirkel, where we made a formal halt to salute the summer daylight round the pole ; and we have dropped some business-men at the mining town of Gellivare. But in the clear morning we find ourselves in a monotonous land of stunted birch trees, of bush vegetation swept by fires, and of dull-green bogs with little lakes. The snow still lingers in the hollows of distant and sparsely-wooded hills. Here, indeed, is Lapland ; and then suddenly in the midst of it we step out at the station of Kiruna into a bright and busy town.

The mountain over against us, quarried and blasted, contains the largest band of iron ore in the world. By the lake of Luossajärvi, a clean wood-built settlement has sprung up, seventy miles within the arctic circle, plunged for a month into polar darkness, with some 8,000 inhabitants, and 1,000 children in its schools. Electric tramways convey the miners to their work, climbing along the flank of Kiirunavaara to points where flights of wooden steps (everything is wooden in this country) lead to the higher terraces and the crest.

The crest is made of magnetite. The band of ore, 3,000 metres long and 100 metres wide, runs nearly north and south throughout the mountain; indeed, it makes the mountain, and passes on beneath the waters of the lake. The smaller band of Luossavaara, parallel with it, lies in lower ground north of the town.

In this lowland the old sediments prevail; they frequently contain detrital iron ore and hæmatitic bands. Some of them are composed of material exploded from volcanoes; others are sandstones and conglomerates. The great zones of magnetite are, however, surrounded by pale syenite and kindred igneous rock. A vein of syenite, with some 60 per cent. of silica, cuts the magnetite, showing that, if the ore separated from the siliceous mass, it solidified while the residual syenite remained fluid. The fine-grained granite on the east of the ore-band, a rock with some 70 per cent. of silica, contains lumps of magnetite. The grey to pink syenite that bounds the ore-band on the west makes an intrusive junction with the ore, and contains odd green nodules, partly hollow, of hornblende, dark mica, apatite (calcium phosphate), and iron ores. These are the broad features of the evidence that has aroused so much discussion.

May not the two magnetite bands be residues of hæmatite-schists caught up in the great intrusion? Quartzites on the eastern side may have enriched the invader with silica, and so produced the fine-grained granite (quartz-porphyry) type of igneous rock. West of the original iron-bearing sediments there may have been volcanic tuffs and lavas of basaltic type; these diminished the percentage of silica in the invading rock as they were successively absorbed, and they left the

green nodules, as recrystallized relics, to show their former presence. The iron-bearing series meanwhile resisted stoutly, but was reduced to a continuous mass of magnetite. Fragments of it remained undigested in the syenite; but the main ribs, as so often happens at igneous contacts, retained their parallelism with the sediments of which they formed a part. Was this the complex origin of the majestic bars of ore on Kiirunavaara and Luossavaara mountains?

This is a somewhat venturesome reading of the present structure of the country, and it is put forward as an example of the suggestions made to us by common stones. There is no doubt that one short visit is not enough to reveal all the difficulties of the problem. But Kiruna has issued a challenge to us. Magnetite is familiar to us at home as small black grains in igneous rocks; here in Lapland it rises up against us with all the dignity of a mountain.

As we descend over the face of the open-works, tier by tier, a great blast goes up, and the ore crashes down upon the talus. We choose one of the specimens of the ironstone-rock, and then take leave of the hospitable Company that develops its industry within the arctic circle. The Lapps themselves, brown and wizened nomads, come from their camp to see us off. Their old-world life, dependent on the reindeer, will survive the electric line and the traffic now dependent on the lodestone.

Another example of massive magnetite-rock occurs in the forest lands of Ontario. Here again we cross or follow foaming rivers and pass the lumberers at their work; in the blackened clearings caused by engine sparks, the large pink flowers of the "fire-weed" are

already bright amid a new growth of birch and spruce. At Sellwood on Moose Mountain, north of the well established mining " camp " of Sudbury, an exposure of black bedded lodestone has been mined.

Its glaciated surface reveals handsomely the essential structure of the rock. As a mineral " proposition " it is held to be rather too siliceous ; there is little doubt that this iron ore series is sedimentary, and has been metamorphosed by fine-grained basaltic dykes and by an intrusion of granite that sends off numerous veins.

Originally there was a succession of sands more or less rich in iron oxides, and the latter have been reduced to magnetite by igneous action. Hornblende and epidate (a hydrogen calcium iron aluminium silicate) have developed in association with the magnetite, and many of the pale veins of granite terminate in green epidote where they die out in the black ore. E. Lindeman ("Moose Mountain Iron-bearing District," Canada Depart. of Mines, 1914) favours the metamorphic view, and ascribes most of the alteration of the original banded sediments to the dykes rather than to the granite. The region may thus have a bearing on the origin of the ore at Kiruna. At any rate, such comparison is always useful. As Charles Lyell used to urge, the first, second, and third requirements of the geologist are " travel." By travel, at any rate, we have felt the attraction of the lodestone.

CHAPTER XIV

A STONE THAT MELTS IN THE HAND

WATER, on the earth's surface, is usually in a liquid form. Yet sometimes, even in temperate climates, it solidifies, it freezes, and for a time is part and parcel of the solid crust. When solid, water has every right to be regarded as a mineral. No one would deny this right to native mercury, though it has never been seen in its natural surroundings in a solid state. Mercury, when cooled to $-38{\cdot}8°$C., crystallizes in octahedral forms ; ordinary earth-temperatures are too high for it, that is all.

The same is commonly the case with water. Yet we are all familiar with its crystals in the form of snow. When water-vapour condenses at a temperature below its freezing-point, that is, when there is so little water-vapour present that its dew-point is below 0°, it produces ice in place of liquid water. There is always a level above us in the atmosphere where this temperature prevails, and where any water-vapour that condenses must do so in the solid state. In our own islands, this *snow-level* is commonly little more than a mile above the sea-level ; on Ben Nevis, at 4,400 feet, we may often experience a drift of snow in summer. Snowflakes are formed of myriads of small ice-crystals caught together

by their surfaces and their projecting bars, and the hoar-frost at the ground-level similarly consists of crystalline spikelets deposited on a cooling surface directly from the passing air. Ice is a volatile mineral; like its molten form water, it gives off vapour from its surface until a certain counter-pressure from this vapour is attained, and the vapour, on a lowering of temperature, condenses again as water, or, if the temperature is below 0°C., in the solid form of ice.

The ice on ponds is also crystalline; the crystals are here plate-like, without well defined boundaries where they meet one another along their vertical faces. They are arranged with the principal axes of the crystals parallel with one another and perpendicular to the cooling surface. Massive ice of any kind is also crystalline. The individual crystals may be in the form of irregular grains pressed against one another without any systematic grouping; but the structure of each granule can be recognized with polarized light,and each granule may be proved to have the same symmetry throughout.

We are familiar with the characteristic type of symmetry in the delicate star-crystals of the snow. These are usually mere skeletons; they have developed rapidly, like the crystals that may be seen under the microscope in thin sections of iron-slags or of glassy volcanic lavas. They have shot out spikes in certain directions, marking, as it were, the general plan, without having had time to fill in all the gaps. But perhaps we can realize the structure all the more clearly in these skeletons. The basis of the little stars and plates appears in most cases to be hexagonal. E. T. Wherry (see *Mineralogical Magazine*, vol. 48, p. 29, 1920) finds

that they are really combinations of trigonal forms, that is, forms with somewhat lower symmetry.

Crystalline water, the mineral ice, has one very unusual property. Water occupies more space in the solid than in the liquid state. In freezing, it expands by about an eleventh part of the volume occupied by it as water when its particles were most closely packed together. This closest packing occurs at a temperature of 4°C. (39°F.). On cooling below this, water expands slightly, and at 0° considerably, the constituents springing into their appointed places in the crystal-structure and apart from one another as they do so.

The temperature of maximum density, of maximum closeness of packing of the water-particles, is, strictly speaking, 3·982°C. At this temperature 1,000 grammes of water occupy a volume of 1,000 cubic centimetres. This is of course the basis of the scientific scale by which standard weights and volumes are brought into relation. At 0° (32°F.), the water has expanded to 1,000·12 c.c., a mere trifle, $\frac{1}{8333}$ part, and yet significant. At this temperature it solidifies, it freezes, and the ice formed occupies 1089·92 c.c.

When water is heated from 4° to its boiling-point 100°, it of course also expands ; but at no temperature before it passes into the state of steam is it less dense than in the state of ice. Water has a density of 1·0000 at 4° ; of 0·9586 at 100° ; and of only 0·9175 as ice at 0°.

Consequently, ice floats in water ; the mineral is lighter, volume for volume, than the product of its fusion. If a solid, when immersed in water, displaces a quantity of water of less weight than itself, it sinks. If it displaces water of the same weight as itself, it neither sinks nor floats ; in such a case its density must be the

same as that of the surrounding water. A given quantity of ice displaces a quantity of water of greater weight than itself, and, therefore, floats. A block of ice weighing 1,000 grammes, if completely immersed, displaces 1089·92 c.c., that is, grammes, of water. It is consequently buoyed up, and comes to rest with only 1,000 c.c. immersed, and 89·92 c.c., or practically one-twelfth of its bulk, above the surface.

The sudden expansion of water at the freezing-point makes it, moreover, a danger to its mineral surroundings. In temperate climates especially, but, indeed, at any place where alternations of frost and thaw are possible, water may lurk in the crevices of rocks and be subject to freezing when the temperature falls to 0°. It has not then time to escape, to push its way out, and to flow over to another spot; the particles move into their crystal-places with such suddenness and insistence that the solid water acts as a powerful wedge. Huge blocks of rock may thus be broken off along the joint-planes of the parent mass; porous stones like chalk may be reduced to a powder of small flakes; and the full measure of destruction is realized when thaw sets in and the disrupted fragments are free to fall apart.

Bismuth and iron resemble water in expanding as they consolidate from a molten condition, that is, as they freeze. But we must fix our attention on the one familiar example, the material of our common stone. Since ice occupies a greater volume than water at the freezing-point, it follows that it will melt if pressure is applied. Heat is used up during this change, and is derived from the ice surrounding the water that is locally produced. When two pieces of ice are pressed together, or even allowed to rest against one another, a

film of water arises, which, as Tyndall says in his *Forms of Water*, " is colder than the ice was before the pressure was applied." The escape of this water relieves the pressure ; " not only does the liquefaction cease, but the water re-freezes. The cold produced by its liquefaction under pressure is sufficient to re-congeal it when the pressure is removed." Hence the two ice-blocks freeze together. This matter was first revealed by experiment, and its explanation was reasoned out by James Thomson, Faraday, and others about the middle of the nineteenth century. The fact of this re-freezing, this *regelation*, is of importance in relation to the behaviour of massive ice ; its proper discussion—for it is not a very simple subject —must be left to physical text-books, and we may specially refer to J. H. Poynting and J. J. Thomson, *Text-book of Physics : Heat*, pp. 201–203, 1906. The important feature from our point of view, the consideration of solid water as a mineral, is that when ice is under pressure fusion sets in, not by a rise of temperature, but by the bringing of the particles nearer to one another, thereby breaking down the structure that is essential to the ice-crystal.

Another point about ice-crystals is that they can be deformed by pressure. A gliding of the particles takes place along certain planes, similar to that recognized in calcite, and a crystal may thus be moulded so as to fit into its surroundings. A transference of particles from one part of a crystal to another may thus take place, in addition to that which shifts them in a liquid state during the process of regelation.

The mineral ice may in consequence respond to pressure in a way that we hardly expect in common stones. As we have already said, the ice-stone is a

collection of ice-crystals with irregular surfaces, fitting into one another, like the crystals in quartz-rock, the quartz of veins. Ice-veins, exactly comparable to quartz-veins, may be seen ramifying in the crevices of rocks wherever frost holds sway.

But there are certain places where ice comes into prominence as the common rock of the countryside. In any latitude where the solid crust of the earth sends up projections above the local snow-level, recesses in these will catch the snow that here falls in place of rain. Light aerial hoar-frost, the substance of the cirrus clouds, will add its solid water day by day. The feathery ice-crystals become packed together by pressure of new material. The snow passes into what Alpine men call *névé*; granular crystals begin to grow in it. These granules increase, both in size and numbers, as the air becomes forced out of the mass; and, finally, an ice-rock results, formed of granules, each one a crystal, which fits closely against its neighbours. We have here the well-known material, glacier-ice.

In Greenland and round about the Antarctic Pole ice is indeed a common stone. We cannot compare it half so well with the water that flows off an ordinary hill as with the rocks that it here conceals. Like them, it is formed of crystalline mineral material; like a quartzite, it is cemented by a substance of the same constitution as its grains; like a shore-deposit, it includes pebbles and irregular blocks dropped into it during its accumulation. The fine wind-borne dust on glaciers, which becomes shut up as strata between the ice-layers of successive snows, is comparable with the sand and mud that are washed out into marine accumulations from the land.

Loose aggregates of tumbled blocks, "stone rivers,"

are known to slide upon a mountain slope ; but the ice-rock as a whole is capable of motion. Various causes co-operate in allowing it to flow under the influence of gravitation. It consists of granules ; though these increase in size as the ice-mass gets farther from the field of *névé* in which it was born, in the lower reaches of a glacier they rarely exceed 15 cm. in diameter. Viewing this character only, the ice-rock may be compared to a coarse sand. If, however, the glacier-grains move over one another, they are recemented by the process of regelation ; moreover, the liquefaction that takes place at the surfaces of adjacent grains transfers particles from one grain to another and enables them to adapt themselves and to continue their motion forward. Particles are probably passed on also by vaporization, condensing as ice-particles on other grains. The individual ice-crystal, moreover, is deformed by pressure. All this allows of glacier-flow.

This flow has far-reaching results. When a massive rock moves over others, as in a landslide, it becomes a powerful agent of denudation. Even the accommodating plasticity of the granular ice-rock cannot prevent it from laying hold of other rocks beneath. Tools, moreover, are given to the glaciers by flaking from the mountain side. With these held in their grip, the familiar valley-glaciers, the ice-rivers of the Alps or of the Canadian Rocky Mountains, pluck off other blocks from irregularities in their beds, while the finer impurities rasp the general floor. Where melting and refreezing can take place in the hollow down which the glacier moves, the constant splitting of the rocks greatly assists the ice in its work of excavation.

The fact that the ice-rock has been studied with such

minuteness in the valleys of temperate climates has made some observers sceptical as to its powers as an agent of erosion. We must, for its true appreciation, look to the regions where ice is the dominant feature of the surface.

In such regions glacier-ice may be unable to receive foreign material from above. It forms the uppermost layer of the country, except perhaps for a few projecting peaks of the former earth-surface, which are too steep to provide a resting-place for snow. Here, as the ice oozes out by gravitation towards the base-level of the country, it gathers in its lower portion all the loose material, and the material that can still be loosened, until the lower third or so of one of these great " continental " glaciers is really a conglomerate of the common stones of the district set in a cement of ice. In Alaska, the huge " moraines," formed by the material left behind where the glacier melts along its front produce hill ranges 2,000 feet in height.

One of the quaintest effects of the physical properties of the ice-stone is that a snow-patch may burrow its way into the ground. So far as I am aware, the credit for the first observation of the process is due to Lieut. Lorange of the Norwegian Royal Engineers (quoted by Amund Helland in *Quart. Journ. Geol. Soc.*, London, vol. xxxiii., p. 164, 1877). Lorange noticed that the base of a glacier in the Jostedalsbræ contained numerous stones lifted off from the floor of the hollow in which it lay, and he suggested that the recurrent freezing and thawing of water in the cracks split the rock and supplied material that was then transported by the glacier.

F. E. Matthes (" Glacial Sculpture of the Bighorn Mountains," 21*st Ann. Rep. U.S. Geol. Survey*, Part ii., p. 179, 1900) has carried the matter further, and shows

how the hollows in which such "corrie-glaciers" lie may have deepened from quite small beginnings. A slight depression in an irregular land-surface, lying near the local snow-level, that is, where freezing and thawing are frequent, receives an infilling of snow. The edge of this miniature snowfield melts when the sun warms the adjacent rocks, and water runs down into the cracks. Freezing, caused perhaps by the mere passing of a cloud across the sun, expands the water; the ice-wedges shatter the solid rock. The snow-patch becomes surrounded by a sludge of broken material, which is soaked through with water during thaw. Everything is ready for a landslide.

One side of the original hollow probably opens on the general slope of a hillside. In any case, the disintegration of the rock is likely to develop an outlet on the downward side. Oozing of the broken rock, and of the mingled snow and rock, takes place. The hollow is freed from time to time by the outward slipping of detritus; it deepens, and at the same time is ready to receive a larger quantity of snow.

The side lying up the hill assumes more and more the character of a cliff. As the broken rock is carried away from it, it is exposed more and more to the vertical flaking action of the frost and thaw. A sort of arm-chair hollow is excavated on the hill.

The giving way of the margins of this hollow allows, as we have said, of the accumulation of more snow. In time the hollow is large enough and deep enough to generate a glacier. The oozing movement of the ice then enables the rock-fragments to be carried steadily away. The blocks thrown down from the growing precipice that forms the back of the "arm-chair" do not cumber the

hollow or lie there awaiting comminution. The familiar form known as a *cirque* has developed through the corroding action of the snow. Matthes has well styled this process of attack *nivation.*

Some of the grandest features of hills that pierce the snow-level are due to the carving out of cirques. The sheer wall of the semicircle, going down a thousand feet or more to the glacier nestling at its base; the grim grooves cut in it by stone-slides, where snow clings for a time before it plunges downward as an avalanche; the tongue of the ice protruding over the rim of the hollow, crevassing from side to side as it makes its exit, and leaving a moraine of frost-riven blocks where it melts far down upon the slope; these are noble but familiar features along the snow-line of all Alpine lands.

In our own islands, the return of temperate conditions has freed the cirques from snow, and we can study in their deserted floors the results of the grinding action where the glacier lay. On Mweelrea in Connemara, on Helvellyn, on the long scarp of Cader Idris, and, above all, among the close-set cwms of Snowdon, the precipiced walls of the great rock-theatres testify in all their sculpturing to the crystalline forces of the ice.

In *Open-air Studies in Geology* (Griffin and Co.; plate 2) W. F. Donkin's fine view of a cirque and "corrie-glacier" near the Matterhorn has been utilized by the present writer. Every stage between this active type and the ice-free cirques of Britain may be studied among the Bighorn Mountains of the forest reserve of Wyoming (paper by F. C. Matthes, above quoted).

We need not go to the wilds of Greenland to find a country where ice is still the common stone. The group of islands known as Spitsbergen has a South Cape that is

only 425 miles from the North Cape of Norway. Pack-ice, our stone floating on the sea, may flow down round the east and south of the islands, when it breaks up during the long days of summer at the pole ; but the warm Atlantic water drifting from the south usually allows free access from June to the latter half of August. In Spitsbergen we have a model combining the features of Greenland and Alaska, and, what is more to the point, a representation on an identical scale of the condition of our own islands during the later stages of the Ice Age. This resemblance is discussed in " Glacial Features in Spitsbergen in Relation to Irish Geology," *Proc. R. Irish Acad.*, vol. 29B, p. 191 (1911).

It is some satisfaction to attain, with little inconvenience to ourselves, a latitude as far north as the northern coasts of Greenland. Fog may have hampered us in the last few days of our northward steaming. The captain of our small vessel—he is, of course, a Scandinavian—ran up a crow's-nest barrel on his foremast before leaving Tromsö, for he knew that we should soon meet the ice. The position from hour to hour has been determined by the compass and the log ; and now we should be in latitude 78°N., and somewhere off the opening of the Ice Fjord.

Our scientific leader, who has been here in all kinds of craft, orders the engines to be stopped. The calm dull sea laps against the edges of the floating ice-shelves, on which seals lie happily, diving off at our approach. The deep blue-green colour of the clefts of the pack-ice suggests the contrasts that lie before us in the great ice-masses of the land. On one of the ice-rafts, a brown cone of shivered rock, looking like a cairn erected by a traveller, shows that some part of the pack was formed

against a shore. The fulmar petrels, clucking like fowls, and swimming round us fearlessly, and the guillemots bobbing up and down, each mother with one chick beside her, tell us also of the nearness of the land.

And then, perhaps at 2 a.m.—time does not matter much in the low continuous sunlight—the fog rolls westward, like a curtain drawn back from the sea. The peaks of Prince Charles's Foreland are the first to show above white sunlit clouds, and in a few minutes more the vast panorama opens, of a land where ice not only covers the hillsides, but floods the hollows and spreads out in glacier-walls against the sea.

We may here spend day after day, extending the notions about glaciers that we acquired in the vales of Switzerland, and viewing in this cold desert the real supremacy of the ice. From the frost-splintered ridge at the south-east end of Dickson Bay we can look over the plateau of Dickson Land, stretching towards Wijde Bay. The snow melts from most of this broad upland in the summer, revealing "nivation hollows," in which its residue lies like gleaming lakes. On the margins of these snow-patches, one may plunge knee-deep into a mud of broken rock and water just above its freezing-point. Cirque-excavation has here begun. The arid surface of the plateau is dissected by the sweeping curves of the cirque-heads, which will ultimately work back until they meet along *arêtes*, like those sought by climbing-men on Snowdon.

Across a valley, and some three miles away, we may note how small glaciers have already gathered in the growing hollows, and how the streams descending from them carry off the detritus that is supplied freely by the

frost (Fig. 15). We know how insidiously rootlets work into a subsoil, wedging apart the blocks, and crumbling a surface that might long have held its own against the rain. Something of the same kind goes on here ; but the agent is one of the earth's own minerals, a mineral that melts in the hand, escapes between the fingers, hides in some crevice, and then, once more solidifying, wrecks the granite rock.

We may now look southward across the waters of the Ice Fjord, and see how small a part is played by ordinary rocks in the lowland landscapes of Spitsbergen. Instead of clays and gravels with streams meandering on their surface, we have what may be called an ice-alluvium, accumulated from snow that slips down from the barren hills. When the white mist creeps in from the Atlantic, ice-crystals are sprinkled on the land-surface, and the broad level glaciers grow by additions from the air. We are reminded of the growth of loess, the fine earth of the steppe-lands, by the gathering, year by year, of wind-borne dust. The ice that floods the lowlands of an Arctic country is to a large extent a wind-alluvium (Fig. 16).

The floating of the ice-rock becomes once more manifest when we pass in a boat along the front of one of the lowland glaciers. Every two or three minutes it sends off blocks, it " calves," as the whale-hunters say, and these blocks plunge into the sea and float away. They fall forward in a cloud of ice-dust, leaving a clear green face on the glacier, deepening in the recesses into glorious blue. Along the crevasses we can look into mysterious depths ; here and there a stream emerges from a course within the glacier, joining the sea by a fine waterfall. The tunnels of larger streams

Fig. 15. Origin of Cirques on Plateau. Dickson Land, Spitsbergen.

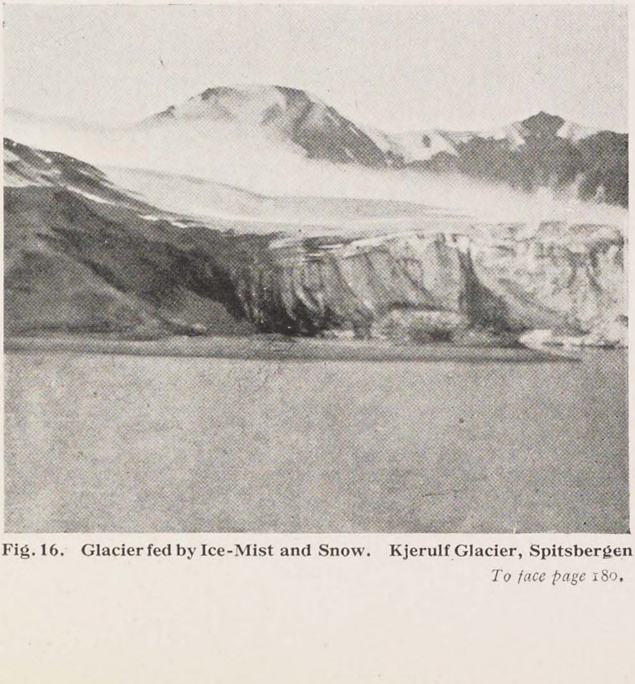

Fig. 16. Glacier fed by Ice-Mist and Snow. Kjerulf Glacier, Spitsbergen

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that flow unseen between the ice-sheet and the lowland-floor open as caves where the glacier's edge rests upon the land. Where it projects, its front is floated up, until larger icebergs break away from it and are carried by the general flow of water to the ocean.

These bergs may show a ninth or so of their bulk above the water-line ; A. Helland, in the paper already quoted, finds that as much as a seventh may be exposed. The icebergs studied by him were in Disko Bay in Greenland. Air-bubbles enclosed in them decreased their specific gravity from 0·9175 to 0·8860. On the other hand, sea-water is denser than pure water, and its specific gravity at Disko was 1·0228. The glacier-ice rose, therefore, out of the water distinctly higher than in ordinary experiments with pure water in a laboratory.

When we leave Spitsbergen towards its autumn "closing time," we may very probably have trouble with the pack-ice gathering round. Leaving the responsibilities of navigation in skilled hands, we may calmly view from our bunks the edge of an ice-raft pressed against the vessel's side ; such light as now reaches us comes down through it, a cold uncertain green. Below the water, the obstacle may spread out in treacherous shelves, like that which wrecked the *Titanic* on her first Atlantic voyage.

The Spitsbergen model, again, reminds us of the more impressive Greenland seas. The giant icebergs off the mouth of the St. Lawrence are known to thousands of our island-race ; but few have seen them in the tremulous moment of their birth. When, a few hours after leaving the damp heat of Quebec, we halt in the fog for their passing, as they drift across the charted course, we may indeed give all honour to the seamanship

that links in safety shore with shore. Then comes a gleam of sunlight, and the superb companion, whose pleasure we have waited, looms ahead, a floating island with peaks and valleys, and streamlets flowing to its cliffed and melting edge. Its pinnacles greet the gold of morning, its caves are treacherous with gloom ; and all this fairyland is just so much solid water—the snow that fell in Godthaab sails to mingle with the warm Atlantic current off Cape Race.

Godthaab, where Nansen made his crossing of the inland ice of Greenland, turns our minds once more to the true importance of frozen water as a rock. The latitude of this region is by no means " high Arctic " ; it is that of Molde and Trondhjem, which are well known as summer-resorts in Norway. The rapids of the Uleå River in Finland, bearing the long " tar-boats " that traffic with the Bothnian Gulf, lie no farther to the south, and to reach the Arctic circle, which in our schooldays we regarded with quite unnecessary awe, we must still travel two degrees to northward. Well within touch, then, of our own latitudes, we have Greenland, a territory as large as the British Isles, Spain, France and Germany put together, where frozen water is the common stone.

And lastly, there are districts where ice forms a stratum beneath the soil-cap, where there is underground ice, above which, with a pleasing nonchalance, the white poppies, and the ranunculuses, and a host of starry flowers, make the brown tundra gay in summer sunlight. We are reminded of the surface of glaciers in Alaska, where forests, and an undergrowth of brambles, have locally encroached on the copious superficial moraine left by the melting of the upper layers of the

ice. Over large areas of northern Asia and northern North America, the low-lying boggy lands rest on subterranean ice. In the tundra there is a subsoil that is of no service to the roots of plants. They can get no water from it, and might as well push for food-stuffs against a quartzite rock. Yet this rock is made of water; its defect is that it never melts. Even in the long days of Arctic summer, the sun's heat has not time to penetrate so far down through the damp overlying earth.

Some of this underground ice may represent the surviving snow-layers of the last great glacial epoch. But it is probable that over all the cold area it is still growing at the expense of surface-waters. Just as a glacier thickens by additions from above, so water, trickling downward, may thicken the underground ice and become fixed as a mineral in the crust.

E. de K. Leffingwell (U.S. Geological Survey, Prof. Paper 109) has recently investigated the process in northern Alaska and the New Siberian Islands. Thawing in summer here extends to about 3 feet down, rarely to as much as 7 feet, and the water fills the joints that open readily in the shifting tundra soil. The ice acts as wedges in these cracks, widening up the passages and uniting at their bases. Blocks of earth may become included; but, as a rule, clean continuous ice-masses result. The soil above becomes lifted on a broad scale, like the soil of our gardens after frost; and the cliffs on the New Siberian Islands show how year by year a layer of the ice-rock becomes added to the permanent crust.

CHAPTER XV

STONES THAT DISSOLVE IN WATER

JUST as the existence of the ice-rock (Chapter XIV) depends on lowness of temperature, so a stone that dissolves in water depends on a deficiency of rain. Meteorologists include snow in calculating the rainfall of a district. They melt day by day the snow caught in their cylindrical gauges, or calculate it as water from its depth on open ground. Hence a place may be described as having a mean annual rainfall of ten inches, although it lies in a region where rain is utterly unknown. The water required in such a district must be secured from deep-seated springs, or else from melting ice; that which falls is solid, and is carried away as ice-sheets till it melts along a genial fringe.

In such a district stones that dissolve in water may exist, on the mountain-peaks that rise above the snow-fields. This is merely because there is no fluid water. But there are many areas of permanent dryness where the temperature would freely allow of rain if there were enough water-vapour in the air. Summer and winter alike—and the winters may be bitterly cold—the water-vapour never reaches its saturation-point. Clouds may drift occasionally and temptingly in blue air some miles above our heads, casting seductive shadows on the

sand; but around our camel-camp the "relative humidity" of the atmosphere, that is, the proportion of water-vapour present to that which might exist at the particular temperature, remains at a low figure and we are not favoured even by a mist. Here is the breeding-place of two soluble minerals that we know as common stones.

We know them as *Rock-salt* and *Gypsum*, products of mines and excavations. The former is one of our necessities, though much is obtainable from the sea; the latter is of great service in furnishing Plaster of Paris for the arts. Rock-salt is sodium chloride, $NaCl$, with trifling impurities of other chlorides, iron hydroxide, sand and mud; these are got rid of by dissolving the material and re-precipitating the pure salt required. Gypsum is hydrous calcium sulphate, $CaSO_4 + 2H_2O$, and is soluble in some 450 parts by weight of water; hence it is not likely to exist where water percolates in the crust. Yet both these stones are cheaply obtainable, and are common even in the limits of the British Isles.

We have said that the desert is their breeding-place; but it must be a desert where water occasionally flows. As we look from our camp, which is pitched on a sun-shattered surface of white rock, we see on the distant ranges the grooves cut by former streams. Even now water may be found in some of them, and in the quiet of night we may hear the murmur of its flow. But these streamlets die away as they leave the heights where clouds occasionally gather, and the sand-cones on the margins of the hills mark their limits on the surface. The water there sinks into the thirsty soil and saves itself by running underground. It spreads in the loose detritus, and perhaps even establishes a "water-table,"

which is tapped in natural hollows or reached by artifice in desert-wells.

From the general water-table, water climbs by capillary action in the vast dry alluvium of the plain. Evaporation sets in as the threads of liquid reach layers near the surface, and the salts brought down in solution from the hills finally become deposited as a cement between the subsoil-grains. The saline residues from long vanished lakes are, moreover, thus brought towards the surface, and in many places sodium carbonate, the "black alkali" of venturesome agriculturists, and sodium sulphate, or "white alkali," accumulate to a dangerous extent. The former of these salts has a deadly effect on plants, and also in a marked degree prevents the soil-particles from gathering together into grains of healthy size. The irrigation of an "alkali-soil" produces an unpleasantly stiff and sticky clay.

Hence even the artificial supply of water to the surface of an arid land may injure the soil for agriculture by allowing of a further climb of salt. Thorough washing and drainage may be required before the material so long accumulated is cleared from the levels accessible to plants; even then, water must not be allowed to stagnate, for it will sink down and return too highly charged with salts.

Under such conditions, obstructive "pans" are frequent (p. 37). In South Africa, on the borders of the Kalahari desert, calcium carbonate may be brought in such abundance to the surface as not only to cement the soil, but to overflow it with thick crusts of travertine (p. 93). In the same region silica, leached no doubt from silicates decomposing elsewhere under tropical rains, is drawn up and forms quartzites

from what might have remained desert-dunes. We cite these examples to show how powerful an influence evaporation may exert in precipitating matter in arid or semi-arid lands.

In such lands the freshwater lakes of former days may still receive water from the hills, but may shrink away below their outlets. Their outlets are now into the air. Consequently the various salts, which play but a small part in the entering water, become highly concentrated in the dessicating basins. The surface of the lake may be maintained at a uniform level ; but the water becomes salter year by year. The familiar facts of the Jordan Valley at once come to mind as an example. The Sea of Galilee is fresh because it has an outlet ; but concentration takes place in a deep valley of subsidence that leads to the deserts of the south. Evaporation has lowered the level of the Dead Sea and allowed the Jordan to cut into its earlier bed, and the fact that the surface of the saline lake is nearly 1,300 feet below that of the Mediterranean is not due to the sinking of the floor alone.

While sea-water contains 3·5 per cent. of salts by weight, the Dead Sea contains about 26 per cent. ; here magnesium chloride happens to preponderate. The result is a density of 1·227 as against the 1·027 of Atlantic water, and in consequence a great power of flotation. Bathers, moreover, when drying find themselves encrusted with salts, and are unpleasantly reminded that crystals have sharp edges and solid angles.

Flavius Josephus (*Jewish War*, book iv., chap. viii. sect. 4 ; I owe the translation to the kindness of Dr. L. C. Purser) says that the water of the " Asphaltitis

Limne" is "so buoyant that it sustains even the heaviest substances when thrown into it, nor is it easy for a person to get down into its depths even if he tries." Vespasian heard of this when commanding the forces in Judæa. He filled up the proper forms for G.H.Q., and authorized himself a journey to the desert country on the banks of the lake. Here, inspired by the true spirit of research, he chose some bystanders who could not swim, and, as an extra precaution, tied their hands behind them. They seem to have been harmless individuals, and were probably recent recruits to the Army. The General caused them to be thrown "into the depths, and it happened that all of them floated as if they were forced upwards by a blast of air."

The salt lakes or *shats* (French, *chotts*) of the northern edge of the Sahara, with their fluctuating shores, illustrate well the struggle between evaporation and supply. The rivers of Algeria and Tunisia, south of the coastal Atlas range, run towards the desert on a fatal course. Where they maintain their flow throughout the year, the unexhausted fertile soil responds. The brilliant green palm-groves of the oases cluster thickly by the streams; their fruit supplies the simple needs of the inhabitants; their timber and the mud of the soaked soil serve to build the primitive mosque and the village, where the flat-roofed houses are set closely along narrow alleys so as to exclude the sun. But a little farther south, where the last vegetation tries to hold its own against the sand, the water runs into broad shallow basins, where some of it soaks away and a large part goes off into the air. The high temperature encourages freedom at the surface of the lakes, and the water-particles stream up in a state of vapour.

They cannot carry with them what they have dissolved, and saline crusts gather on the barren shores.

A shat is subject to considerable variations, and in summer practicable and recognized routes may run across it. Some of these look very tempting on the large-scale maps published by the French Survey for Tunisia. Black lines, marked Trik el Oudiania, Trik Zitouna, and so forth, boldly traverse the blue water; but we are given to understand that these routes must be closely followed and always with a guide. Norman Douglas, writing of the great Chott Djerid of Tozeur in his *Fountains in the Sand* (1912), quotes an Arab account of a lost caravan. "Unfortunately one of the beasts strayed from the path, and all the others followed it. Nothing in the world could be swifter than the manner in which the crust yielded and engulphed them; then it became like what it was before, as if the thousand baggage camels had never existed." Douglas then describes the great saline swamp in sunlight. "The surface is rarely lustrous, but of a velvety texture, like a banded agate, mouse-colour or liver-tinted, with paler streaks in between, of the dead whiteness of a sheet of paper; now and again there flash up livid coruscations that glister awhile like enamel or burnished steel, and then fade away. These are the fields of virgin salt which, when you cross them, are bright as purest Alpine snow."

Since salts have various degrees of solubility in water, the deposits thus encouraged must have a certain sequence. A time comes early in the history of a salt-lake when no more calcium carbonate can be retained. "Calcareous tufa," a form of travertine (p. 93), begins to encrust the floor. Calcium sulphate, the source

of " permanent hardness " in water, separates out next as gypsum, taking to itself two molecules of water to every one of sulphate. Ultimately, as in the Dead Sea, sodium chloride is deposited, as cubic crystals and massive layers of rock-salt; and lastly, in normally constituted natural waters, the chlorides of magnesium and potassium mark the disappearance of the lake. In this last phase, we are dealing with cases where even the channels of supply, and not merely the outlet, have run dry. The lake, as a topographical feature, vanishes, and its site is marked by a gleaming pan of salt.

But often the history is not so simple. Water may stream in and renew the lake's youth after it has reached the gypsum stage. This event may be recurrent in semi-arid climates, and bed after bed of gypsum may be laid down, while the rock-salt stage may be indefinitely postponed. The climate may meanwhile change sufficiently, and the lake-level rises to its ancient outlet; it overflows, it becomes fresh water, and herds of wild horses or of antelopes seek the rich pastures on its shores.

The story of lagoons is similar (Fig. 17). Where the sea splashes in, or wells up over some sand-spit at spring tides, or perhaps across a fringing coral bar, pools of concentration are left upon the landward side. Chemical reactions go on in these lagoons as the mixed salts act on one another, especially in the high temperatures of the tropics; and a series of " stones " are here formed from solution, and may be preserved by runs of estuarine mud brought down by some freshet from the land. We have said enough to show how stones that dissolve in water may yet arise in water under arid

Fig. 17. Evaporating Lagoon, with Footprints. Nr. Sousse, Tunisia.

Fig. 18. Forest Decaying in Swampy Ground. Turenki, Finland.

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and semi-arid conditions; they thus become added to the stratified series of the earth.

When, therefore, we dig out gypsum or rock-salt from the crust, we look around for evidence of arid conditions in the past. The Triassic rocks of our islands offer a notable example. In these strata, which are mostly red sandstones and red marls, our great deposits of rock-salt lie; and, though we may sink through bed after bed of gypsum without finding rock-salt, the presence of rock-salt may reasonably make us look for gypsum. No traces of marine organisms occur in these beds; the shells of a small phyllopod crustacean, Estheria, which still lives in fresh and brackish water, extend the evidence; and the preservation of amphibian footprints, of ripple-marks, and of sun-cracks, as casts in the successive fine-grained layers, strongly suggest lake-shores, exposed to long epochs of drying through fluctuations in the supply of water. These are the associations of our gypsum and rock-salt beds in England.

In a grey day of the Midlands, when the smoke of a neighbouring coalfield blackens the red sandstones in the cuttings through the hills, we may look back to white lakes spreading beneath the sunlight; to cycads, like dwarf palms, clustering along the river-grooves; and to great bipedal amphibians leaving their tracks in the quickly drying mud, as they emerge on salt adventures through a green fringe of horse-tails on the shore.

It is perhaps time that we regarded these two stones, gypsum and rock-salt, from a mineral-cabinet point of view. Gypsum is clear and colourless, furnishing snow-white masses by the aggregation of its crystals.

Each crystal has one prominent cleavage ; this feature catches the eye as the stone is turned about. Gypsum is so soft that it is scratched by the thumb-nail ; the massive rock formed by it, and known as *alabaster*, is thus not so suitable as limestone for carved work that is liable to be rubbed. Obviously it would not do for external decoration, owing to its solubility, even in the purest rain. On a shore, or on Alpine shelves, its blocks and strata-edges become channelled out by natural waters in the smooth forms that we also know in limestone ; but the process is far more fatal for the mass. Alabaster is thus not a marble to be considered for general use ; but its translucency, and the delicate veining sometimes imparted by iron hydroxide, give it a beauty of its own for internal carved work, such as balustrades and even statuary.

Magnificent crystals of gypsum, some feet in length, have been found among the deposits of the Great Salt Lake of Utah, which is a shrunken remnant or a revived representative of a far larger inland sea ; and small but choice specimens develop in fossiliferous clays, through the interaction of the sulphuric acid from decaying iron pyrites, iron disulphide, on the calcareous matter of the shells.

Apart from its lower hardness, gypsum may be distinguished from calcite by simple chemical means. It does not effervesce when acid is dropped upon it. Both minerals impart a red tint, due to calcium, to a bunsen gas-flame or to an invisible blowpipe-flame. The presence of sulphur in gypsum can be ascertained by a well known if roundabout reaction. This serves as a good example of the ingenuity of the older mineralogists, to whom a candle, a blowpipe, a stick of charcoal—

which very often cracked and swallowed up the experiment—and some seven or eight simple reagents, formed a laboratory-equipment by which species after species was assayed. Sulphates when merely heated will not readily yield their sulphur ; it is of no use, for instance, to look for it as a yellow deposit on the cooler part of a hot tube, or to smell for it, with a whiff of anxious apprehension, in the form of sulphur dioxide at the outlet of an open tube, in which the " assay " is brought under the influence of a flame.

Powder the mineral, however, with sodium carbonate, and fuse it well on one of our modern compressed charcoal blocks in the luminous " reducing flame " that is the joy of the true artist with the blowpipe. On thorough reduction, sodium sulphide is thus formed, and this evolves hydrogen sulphide (sulphuretted hydrogen) when touched with water. Note here that the sulphur has been pulled out of the gypsum and combined with sodium that has been pulled out of its carbonate ; on moistening, the sulphur is again extracted, twice divorced, as it were, and joins with hydrogen obtained from the decomposition of the water. Hydrogen sulphide is broken up by certain metals, making characteristic sulphides with them. Take, then, the slaggy mass from the charcoal, press it out with a drop of water on the surface of a silver coin, which has been previously cleaned with a handkerchief from any taint of currency ; a black stain of silver sulphide immediately results. The final and conclusive union has been effected ; after two intermediate stages, the lure of the precious metal has secured the sulphur of the gypsum.

Rock-salt, known to refined Americans as Halite, crystallizes in colourless transparent cubes. Its taste

is, of course, familiar, though a cultured mineralogist should not lick museum-specimens laid out for his admiration. The same taste, however, is afforded by the much rarer and much more valuable potassium chloride, the mineral Sylvine, which crystallizes in the same forms as rock-salt. Sylvine, however, colours a bunsen gas-flame violet, while the sodium of rock-salt, of course, gives a magnificent yellow flame, which is accepted as a standard colour for numerous optical measurements.

It is interesting to demonstrate the presence of chlorine in both these simple compounds. Here, again, the ingenious blowpipe provides us with a pleasing test. Copper chloride is distinctly volatile when heated, and yields a beautiful blue flame, which passes into green where the chloride breaks up and copper oxide takes its place in contact with the air. I do not know who discovered the virtues of " microcosmic salt " (hydrogen sodium ammonium phosphate) as a flux ; it was used by assayers for metals—surely by the alchemists, if its name may guide us—before Jöns Jakob Berzelius, the Swedish chemist, introduced it to mineralogists about 1820. To make a good bead of this very fusible and bubbling salt on a loop of platinum wire is one of the triumphs of a wily demonstrator. When such a bead is secured—the phrase is quite a euphemism—a small piece of copper wire is fused into it. Then a fragment of rock-salt or sylvine is added ; its chlorine combines with the copper, and the blowpipe-flame beyond the heated bead is coloured a magnificent blue. In the semi-darkness of winter afternoons, there are few more charming employments than a course of qualitative analysis with the blowpipe. Let the chemist avoid

a gas-jet, order a supply of good stout candles, and go back to the simple life and the fundamentals of the old enquirers.

The lumps of gypsum and rock-salt ready to our hands are often marked by earthy stainings. We must come out again from the cabinet, and down into the strata where these are common stones. The solubility of both rocks promotes sink-holes at the surface, and the wood-framed houses of the salt-mining area in Cheshire bear witness to the insecurity of their foundations. It is well, in a country subject to earthquakes or subterranean solution, to have a dwelling that will warp and tilt, rather than one that will crack and crash about one's ears. Some of the picturesque ponds on Triassic lands in Shropshire are due to the falling in of the ground where gypsum beds occur beneath. In such spots the waters dissolve the stones, and the rock is removed out of its place. Considering, indeed, how freely water permeates the crust of the earth, it seems remarkable that anything soluble in water should survive. Mines are proverbially wet; their tunnels traverse crack after crack, even among igneous rocks, from which subterranean water oozes; and the pumping-engines are required, not so much for the return of local rain-water to the surface, as for bringing up water that flows in from below. Here and there the workings cut across veritable torrents, and at times, as in the Simplon tunnel, the inrushing water is unpleasantly warm from its long and deep sojourn underground.

Yet there are regions that may be called subterranean deserts, from which water is excluded, and here salts that were protected in the first instance by layers of impermeable mud may remain for long geological ages

as a record of the arid days. A salt-mine, compared with a coal-mine, is a sort of paradise. The toughness of the mass enables huge halls to be carved out, the walls of which glisten at the approach of candles, or in the modern glamour of electric light. Mining in an ordinary mineral lode is often quite a clean adventure ; but the passages are liable to be tortuous, and the richness or poverty of the veins control the width of the excavations. In the best of circumstances, the visitor may find himself ascending from level to level by ladders that terminate in unfamiliar holes, with water falling on the top of him and the smoke of the last blast catching at his throat. But in a salt-mine all seems arranged for his delight. The " skip " transfers him swiftly four hundred feet or more below the surface, and he steps out into a " mineral vein " that may be a hundred feet in thickness.

Sixty feet are perhaps excavated from floor to roof, and forty feet, proved in the shaft, are left above, until the lateral workings are completed and it is time for brine-pumping to begin. The splendid halls are then abandoned, water is run in, and the collapsed roof is brought up in solution. This, in brief, is the story of many salt-mines, in which the miners walk about, and wield their picks, and push their trucks, working within the mineral, as happy as a mite in cheese. The very existence of the salt proves that the roof and walls are dry. The rock when brought to the surface must, of course, be sheltered from the rain. The " ore " from this type of mine dissolves in water.

Great thicknesses of salt imply long constancy of the conditions under which the ancient lake

dried up. Frequent alternations of thin bands of salt and gypsum, red desert sands blown in, red muds washed down by sudden rains, record the varying weather of a climate arid on the whole. Those who love to read the history of their district may find an interest in these changes; but the miner in such cases has recourse to brine-pumping and no more works in crystal halls.

CHAPTER XVI

A BLOCK OF COAL

SOMETIMES in a valley of Glamorganshire, where miners in occasional hours of leisure discuss economic problems in the shelter of ancestral hills, the atmosphere of philosophic calm is broken by the rumblings of assault. Thomas Griffiths has expressed his differences with John Jones of Abergorchwy by projecting a missile at his head. " He heaved a lump of coal at him," says a neighbour, with a certain grim appreciation. Griffiths has realized that coal is a stone, and has put it to the primitive use of all such materials in the hands of irresponsible supermen.

Though there may not be as much coal in the earth as we should like, it forms an important part of many stratified series. Scientific interest will always attach to it as evidence of former vegetation. Its essential constituents, carbon, nitrogen, oxygen, hydrogen, have, in the vast majority of instances, come to their present combinations through a vegetable form. Yet it is obvious that, if we trace things far enough, these substances were originally part of the consolidating earth. The gases of the atmosphere may have been occluded in the metals of the core, and the carbon

dioxide that streams out to this day from volcanic centres, and gives a sparkle to the springs of Bohemia and the Rhine, has no connexion with decaying organic matter. It is nascent, "juvenile," as Suess says, and has only now begun to run its course.

Hence in certain places rocks rich in carbon, or consisting entirely of carbon, may have arisen from the primitive substances imprisoned beneath the crust. *Graphite*, the soft mineral form of the element carbon, sometimes contains, as in the Western Alps, traces of the stems of trees; but in many cases it occurs as irregular masses associated with crystalline rocks, and seems to have preceded them, or to have originated with them, far down below the surface.

In Borrowdale in Cumberland, graphite, the black lead of our pencils, is associated with intrusive igneous rocks. Diamond, the hard form of crystallized carbon, similarly suggests an inorganic origin. In South Africa it has been traced to crystalline rocks called eclogites, which are, in all likelihood, the altered representatives of sediments and igneous masses, boiled together in some deep-seated cauldron of the earth. The diamonds may have travelled into the eclogites from the nickel-iron core still farther down, since diamonds are known in the iron meteorites, portions of disrupted or unconsolidated planets, which come to us from outer space. Graphite is, moreover, common in meteorites, and small diamonds are left behind when the iron masses of Cañon Diablo in Arizona are dissolved in acid. These worn and pitted lumps of iron, found upon the surface, are generally regarded as fragments of a meteorite; but it is possible that they were ejected from the lower regions of the crust. Diamond, then, and graphite

also in certain cases, point to the existence of primitive stores of carbon in the universe.

There is, moreover, some uncertainty about the origin of the coaly matter that is here and there associated with very ancient strata. As will be mentioned presently, our knowledge of land-floras does not go back beyond Lower Devonian times. Banks of seaweed may have been responsible for the rare coals in earlier systems ; but it is hard to find an organic origin for the seven feet of coal interbedded with pre-cambrian sediments in Olonets in north-western Russia.

The compact and gaseous coals styled *cannel*, because they burn freely like a candle, may be, as H. Potonié says, in large part "sapropelic." That is, they seem to represent the infilling of swampy lakes, where decaying animal matter from the small fauna of the lake—crustacea and so forth—has contributed to form a slimy mass, in which algæ are associated, as well as other vegetable remains drifted from the shore. Even marine organisms in land-locked bays may have given rise to cannel coal in very early times.

The great bulk of coal, however, has originated in some way in connexion with the growth of plants on land. Though this black stone itself rarely shows vegetable remains to the unaided eye, owing to their having been in a state of fine division and decay before the material settled down, yet the beds of shale and sandstone associated with coal-seams often yield delightful specimens. In the sandstones these are usually in the form of internal moulds of hollow stems ; but in the impervious muds delicate fern-like fronds are beautifully preserved. In such layers the plant-remains have been drifted apart, spread out, as it were,

for study, and then quickly covered over by inorganic matter. The fact that they fell into muddy water has been the main cause of their preservation.

It is not difficult to trace a connexion between these fairly separated specimens and massive coal. Again and again the lower parts of the stems of great trees, sending out their roots into the clays, are found in what is called the " seat " of coal-seams. The coal-seam above represents the remainder of the stems, the ramifying branches and the leaves, that fell down together into the swampy soil and lost most of their individual characters in decay.

The association of coal with swamps, and in many cases with the marine deposits of a shore, seems natural when we remember how rapidly dead trees decay. When walking through a primæval forest, where the old timber has fallen year by year, we must be careful where we step, and certainly not trust to mere looking at a log before we leap. Perhaps the cut sleepers on a colonial railway, the only stepping-stones in a roadless country, may give us thought enough as our stick sinks in three inches. In the open country, oxidation of the wood-substance takes place still more freely, and the wind blows away the ash of the unseen aerial combustion. A damp earth, and even bog-conditions, are required to prevent total loss.

Even then, as we know, it is not the original wood that is preserved. Its constituents, ranged in order of their percentage weights, are carbon, oxygen, hydrogen, nitrogen. All these pass off in gaseous combinations; the production of coal depends on the relative retardation of the loss of carbon. It is not good, from our human point of view, that all the hydrogen, an inflammable

gas, should disappear. In natural rotting under coal-making conditions, the oxygen shows by far the greatest loss, the percentage of carbon increases greatly, and the percentages of hydrogen and nitrogen remain much the same as in the wood. There has been a loss all round; but the carbon has been most resistant.

We may quote from the *Encyclopædia Britannica* (11th ed., vol. vi., p. 576) two analyses, calculated with the water, sulphur, and ash excluded. We have here, following the original analyses, separated the oxygen from the nitrogen.

	Brown Coal. Styria.	Household Coal. Dudley, Staffordshire.
Carbon . . .	55·11	79·70
Oxygen . . .	36·05	13·07
Hydrogen . .	5·80	5·37
Nitrogen . .	3·04	1·86
	100·00	100·00

Brown Coal is the first stage in the chemical series from wood to graphite. Ordinary wood contains about 50 per cent. of carbon.

The fact that half the weight of timber, and eight-tenths of the weight of our common brightly burning coal, consist of carbon makes us ask where plants obtain this large supply. Is it in the air or the earth? Most assuredly in the air. Carbon streaming out of the earth as a "juvenile" product, or from the decay of organic matter or of coal, is mostly united with oxygen as carbon dioxide. This gas is also breathed out by almost all living things, animal or vegetable, while green vegetation gives off oxygen also.

The quantity of carbon dioxide in a given volume of

the lower atmosphere, where it is most prevalent, may seem small; by volume it is only 0·03 per cent. But this is sufficient to supply carbon to the multitudinous variety of common plants. Animals prey on these plants and obtain their carbon from them. Even completely carnivorous creatures thus ultimately depend on plants, and the plants depend on the carbon dioxide of the air.

How is this carbon fixed in wood and coal? The matter is far too interesting and too intricate to be dismissed with the popular phrase that coal is "bottled sunlight." The sun supplies the initial energy, and part of this energy comes to us in the form of heat when we finally burn the coal; but there are very complex stages in between. Light is required for the primary action. Minute green protoplasmic bodies, capable of multiplying by division, lie within the protoplasm of certain of the plant-cells. The green substance in solution in them is called chlorophyll; but this merely means "green leaf," and explains nothing in itself. Chlorophyll strains off certain of the rays of white light; these supply the energy that starts the chemical reactions.

The air enters the plant-tissue by little pores in the leaves, and gets into the maze of passages between the underlying cells. Oxygen passes in, as in the case of animals, and carbon dioxide passes out. But the carbon dioxide present in the atmospheric air is caught in the cells where the chlorophyll corpuscles occur; it is split up, and by combination with hydrogen obtained from water in the cells, forms as a rule the important food-stuff sugar. At the same time, as a provision for any period when more sugar may be

needed, the excess sugar is converted into another "carbohydrate," starch, and is retained, like a store of raw material kept in reserve by a careful caterer. The plant-activities reproduce sugar from it, and pass this in solution through the tissues as a food.

The chemistry of the processes is not yet understood; but the ultimate result is that carbon compounds are built up in the solid portions of the plant. To sum up what we have said, in the presence of light the chlorophyll corpuscles are actively engaged in breaking up the carbon dioxide drawn in with the other gases of the atmosphere. Oxygen is returned to the common air; the carbon is retained.

The increase in the proportion of carbon during the passage from wood to coal can be traced in all its stages, and under certain circumstances *anthracite* results, with a residue of over 90 per cent. of carbon. This is the common coal of our South Wales coalfield. Though for adequate burning it requires a special stove, it has immense advantages in being clean, and in not contaminating the air above the chimneys. The contrast between New York, where this "hard coal" is burnt, and Albany, 145 miles away, which uses "soft coal," is obvious to new arrivals in the busy successor of Fort Nassau. The pavements of Llandaff and Cardiff, again, testify to the cleanness of the rain that falls there.

Anthracite does not soil the fingers. It is harder and denser than ordinary coal, and has a brighter and almost metallic lustre. The old view that anthracite is coal that has suffered from metamorphism, and that

its presence depends on the folding of strata, is not sustainable, and in South Wales anthracite and common coal occur in places in the same seam.

The ash of anthracite is sometimes said to be less in proportion than that in other coals; but this statement is not borne out by a wide range of analyses. It is highly likely that the type of vegetation producing anthracite differed from that producing common coal, and that this type allowed of a more ready loss of gases in its decay. This matter is well discussed by E. A. N. Arber in his *Natural History of Coal*, a small and handy volume published in 1911.

Common coal, *humic coal*, as is well known, soils the fingers, and its winning and storing at the earth's surface conduce painfully to grime. The quantity of coal ejected as fine unburnt dust into the atmosphere by our wasteful methods of combustion darkens the air over the English and Scottish midlands. For miles to leeward of an industrial city the grass and the sheep of the high pastures become blackened with this stain of civilization. The iron pyrites associated with many of the coal-seams gives rise to sulphuric acid, which attacks the limestone blocks of buildings beneath their accumulated sooty crust.

Now that the general rise in wages has improved the position of the toiler of the fields, the food-producer in the open country may perhaps feel himself happy in comparison with the great food-consumers, the dwellers in our sunless towns. The chemical and physical characters of coal have much to answer for; and the conditions under which a substance of such general use is raised from the interior of the earth render one more charitable (within the bounds of patience)

to the demands so insistently made by its extractors.

The name " humic coal " is used by Arber, following David White, in preference to " bituminous," since bitumen is a general term for petroleum and asphalt, substances not found in common coal. A fragment of coal usually shows a delicately bedded structure, brightly reflecting layers alternating with duller ones. Sometimes a fine meshwork of fibres occurs, known as " mother of coal," the French *fusain*, and these reveal woody tissues under the microscope. Marie C. Stopes has published (" Studies in the Composition of Coal, No. 1," *Proc. Roy. Soc.*, Ser. B., vol. 90., p. 470, 1919) the first part of an investigation of the bright and duller constituents of coal, in which she shows that the former consists of two distinct types of substance. One of these, " clarain," is largely made of translucent spores, with tissues of stems and leaves, while the other, " vitrain," though translucent, is structureless. The duller harder material, " durain," is largely made of closely-packed granules, with some clearly recognizable spores. The four materials that are thus distinguished by Stopes may occur together in small specimens of coal ; fusain and durain may lie like broken fragments in a ground of clarain, while vitrain tends to form beds distinctly bounded above and below.

It is early to draw conclusions, and we must not anticipate the author ; but it has been made clear that a separating action of the decaying vegetation has commonly taken place. This is only to be expected, in view of the importance of the presence of water for the formation of any coal at all.

Lowly vegetation that flourishes in damp places is likely to be converted into brown coal, and ultimately

into humic coal. The abundant mosses that spread into lake-hollows and in course of time choke the waters give rise to peat-bogs over hundreds of square miles of country. They foster a continuance of damp conditions, and such conditions penetrate the forest-lands. A damp undergrowth encourages further dampness, to the detriment of the older trees. The timber rots, and its remains are entombed in the oozy ground (Fig. 18). Peat, which is formed of a sphagnum-association rather than entirely or mainly of sphagnum moss, in time triumphs over the woodlands.

The bleached upright lower stems of trees, and their ramifying roots, are found at successive levels in the peat-bogs. The great thickening of the peat sometimes defeats the very plants that form it; under the drying action of the wind, the uppermost layers are partly freed from moisture. Grasses and heather, rather than water-loving mosses, spread over the surface, and provide a soil on which the seeds of forest-trees may fall. It does not seem necessary to suppose a change of climate to account for every change from a régime of timber to mosses, and then from mosses again to timber, as is often revealed in the layers of a bogland.

The great bulk of coal, however, is not to be explained so simply. The coal seams are not the fossil representatives of peat-bogs, but record the fall and decay of trees. Swamp-vegetation on a sinking shoreline will very probably give rise to coal. If subsidence is continuous and the conditions remain uniform, a massive seam 200 feet in thickness may arise. Such conditions, however, are very rare, and frequent alternations commonly occur.

Sometimes, when the material of a seam has accumu-

lated for a few feet, a run of mud from the overflow of a river provides the cover that interrupts and yet preserves it. At another time, there is a marine incursion, and sea-shells are found in the sands or clays above the coal. It is not necessary to suppose that primitive vegetation as a whole preferred estuaries and sought a life of humidity and gloom ; it is only the vegetation crowded into these conditions that has been preserved to us as serviceable coal.

There are, however, some plants that can grow upon sea-margins, and these are, of course, all the more likely to be entombed before decay. The favourite example with all writers on coal is the group of mangroves, or rhizophoraceae, trees growing in the tropics, and giving off extra roots from some distance up the stem, and even from the branches. These roots penetrate the soil and send up shoots that become new trees. The mangroves can flourish in salt estuaries, and a mangrove-swamp bids fair to repeat, with its intercalations of marine sediments, the features that characterize so many of our coal-measures. The trees forming the Carboniferous seams were, however, not of the mangrove sub-class, or even ordinary phanerogams, and the analogy is useful merely as illustrating how plants that can stand salt conditions are in a favourable position for preservation.

A mangrove-swamp is one of the quaintest places to stroll about in, especially when, as on the lagoon-edge of Kilindini, the fish (Periophthalmus) come out and climb with their fins on to the convenient arches of the roots, bask there in the sunlight, and regard the stranger with protruding eyes that also act as ears. This, however, is a bypath, not to be encouraged

by the editor; it leads us far too far away from our study of a block of coal.

In the British Isles we regard coal as an essential feature of the upper part, at any rate, of the great system of rocks that lies between the Old Red Sandstone and the Permian. In some regions this system is represented entirely by marine deposits; but, taking the world as a whole, it has been justly styled "Carboniferous."

In Devonian (Old Red Sandstone) times, the first known land-floras spread upon the continents, and, as F. O. Bower has recently told us ("The Earliest Known Land Flora," *Nature*, vol. 105., p. 681, 1920), until 1913 the plants of early Devonian times were very imperfectly known. J. W. Dawson's Psilophyton, described from Canada and Perthshire, was regarded as an ancient club-moss; but its structure and affinities have been determined only in the last few years by discoveries in Scandinavia and Aberdeenshire. Its remains reveal ancestral characters linking perhaps the mosses and the ferns.

The land flora of Upper Devonian times is far better known, and carries us on to the forests of ferns, club-mosses, horse-tails, and of seed-bearing though fern-like trees now known as pteridosperms, that went to make our common coal. The rapid spread of this flora round the globe is due no doubt to its simple modes of reproduction. Though composed of lowly forms that grew to the size of forest-trees, these forms gave rise to spores, the very abundance of which secured the continuity of life. The links between the early plants propagated by spores set free from the parent plant and those in which the female spore awaits fertilization on

the tree are interestingly stated by D. H. Scott in his *Evolution of Plants*, p. 123 (Home University Library).

Though plants as high in the scale as conifers and cycads occurred in Carboniferous times, and large beetles boomed in the damp darkness of the woods, no honey-sucking insect has been found. None of our familiar flowering plants had yet developed to brighten the undergrowth and to spread beyond the margins of the woods.

In succeeding periods, coal seams were formed, where the conditions were favourable, but never with such world-wide abundance as by the unspecialized flora of Carboniferous times. Forests composed of far more modern types of vegetation, containing genera that are common at the present day, have, however, furnished thick seams of coal to the northern lands of North America. In Canada, Lower Cretaceous coal, both humic and anthracitic, occurs in the Rocky Mountains and in British Columbia. Upper Cretaceous coals are found on Vancouver Island and along the Pacific coast. Valuable lignites of Lower Cainozoic age are mined, as well as coal, in Alberta and Saskatchewan, on what may be called the populous side of the divide.

In the United States, apart from the immense reserves of Carboniferous coal in the folded beds of the Appalachians, North Carolina and Virginia possess Triassic and Jurassic seams; the Upper Cretaceous coals of the Laramie lake-deposits in the high plains of Wyoming represent an epoch when palms grew side by side with the oak, the poplar, the eucalyptus, and the plane.

In Gippsland, east of Melbourne in Victoria, there is good coal of Jurassic age, and brown coal also abounds in this district and inland on the Murray Plains. The

Gippsland brown coal accumulated, like that of Bohemia, in Cainozoic lakes, and is of altogether extraordinary thickness. In one boring traversing 995 feet of strata, 781 feet consist of coal, three of the seams being respectively 227, 265 and 166 feet thick. After this, the "Mammoth seam" of 20 feet in the Carboniferous beds of Queensland looks quite small; it may be noted in passing that most of the Queensland coal is of Triassic and Jurassic age.

There is a great lacustrine field of Jurassic coal in Siberia, near Irkutsk, and much of the supplies of central Europe, notably of Austria and Bohemia, come from basins of brown coal, formed in Eocene, Oligocene, and Miocene times. In northern Bohemia, the great excavations, open to the day, and associated in the landscape with dominant and craggy relics of volcanic cones, form a striking contrast with the grime of the Carboniferous coalfield that stretches through Silesia and across the Polish frontier.

In spite, however, of these younger resources, the coal formed by the great development of the humbler types of vegetation in Carboniferous and Permian times is looked to as the basis of mechanical industry in all quarters of the globe. "Permo-Carboniferous" beds supply the comparatively thin seams of South Africa; 96 per cent. of the coal of India is of the same (Gondwana) age, and amazing thicknesses are rumoured from districts that so far have not been reached by railways.

China finds its best prospects in Permo-Carboniferous strata, though coals occur in all the succeeding systems, with the exception of the Cretaceous. The greatest coalfield of Russia is that of the Donetz basin in the Cossack country lying north of the Sea of Azov.

Carboniferous forests are here recorded by thirty to forty coal-seams, in strata that gathered in estuaries opening on a sea. The Donetz coal-basin measures 230 miles in an east and west direction, and in parts is 10 miles wide. About a third of the reserve is humic coal and two-thirds are anthracitic, the total being estimated as fifty-three thousand million metric tons. This is written in words, so that there may be no mistake about the noughts. The total, including "possible," reserves of all the fields of England and Wales together are only about three times this quantity. The output of the Donetz basin began with 98,000 tons in 1860, and in 1911 alone it reached 20,000,000 tons. (*Coal Resources of the World*, Geological Congress, Toronto, 1913.)

Coal, from the scientific point of view, cannot be regarded as a mineral, since it has no constancy of composition, and no possibility of a crystalline form. But it is clear that it plays a large part as a stratified rock in the earth's crust, and through general use is the most familiar of the crude products of our mines. Our liberal methods of consumption, and the increasing demands of clamorous industry, make it certain that this chapter will soon be out of date. Thanks to the quality of the paper selected by Mr. Melrose, a copy of this book may be found by the curious a century hence in the British Museum library; but coal will then be classed with the precious, not the common, stones.

CHAPTER XVII

ON MILLSTONES

THOUGH the milling of flour by stone is practically extinct among mechanical peoples, the selection of millstones was an important business well on into the nineteenth century. The hand-quern survived until recent years in the outlying Hebrid Isles, and the pounding of corn by a rounded stone against the hollow or plane surface of another is a prevalent female industry among myriads of primitive folk.

Obviously a millstone, to be effective, must be to some extent gritty, or, as we may say, " raspy " ; on the other hand, it must not break down into powder and add its substance to the flour. Well cemented sandstones offer themselves in many countries ; but quartzites, sandstones cemented by silica, are likely to wear too smoothly, and are, moreover, difficult to shape.

All across England, and into the great coal-basin of South Wales, a sandstone series underlies the true Coal Measures, and geologists have adopted for it the quarryman's name of " Millstone Grit." As our boatman guides us down the narrows of the Wye between Tintern and Chepstow, some old millstones may still be seen

upon the eastern bank, probably of local manufacture from a grit at the base of the Coal Measures high up in the Forest of Dean.

The Millstone Grit of British geologists is a remarkable group of sandstones, some 5,000 feet thick in the midlands, thinning southward, and represented in the far north, towards the Roman Wall, by alternating beds of shale and sandstone with a maximum thickness of only 500 feet. As a stone it has been studied in much detail, with a view to tracing the origin of "such quantities of sand."

The Lower Carboniferous ocean, which invaded the greater part of England, central Scotland, and probably the whole Irish area, was shifting gradually to the east. Its continuous deposits of organic limestone are so finely displayed in the gorge of the Avon below Bristol as to cause A. Vaughan's name, "Avonian," to be adopted for the whole Lower Carboniferous series. As the upheaval of the sea-floor steadily went on, huge shore-deposits spread across the limestone; this was the first indication that our region was about to furnish delta-land, on which the forests could flourish that ultimately provided coal (Chapter XVI). The transition from clear sea to estuaries is marked by the formation of shales, and by the broad sandbanks of the Millstone Grit.

The materials of the grit must have been worn from neighbouring land, and it is always interesting to trace in a stone the geography of ancient days. The "palaeo-geographic" maps thus constructed are quite unlike any map recording modern features, since none of the picturesque details of jutting capes, drowned valleys stretching inland, or dissected plateaus rising above

coastal plains, can be inserted from the highly generalized information gathered by a century of research. We may be sure that such attempts resemble Martin Behaim's globe of 1492, which shows a continuous ocean from the west to the east of the Old World, because the New World was not then known to block the way.

None the less, geologists can say with some assurance that at such and such a period land lay on this side, open sea on that, and the mineralogist, working on the sedimentary grains in default of larger pebbles, can even tell us something of the rocks that lay up country.

In the case of the Millstone Grit, we have the evidence of both sand and pebbles. As an example of how the geographical question may be studied in a stone, we may cite a recent paper by A. Gilligan on "The Petrography of the Millstone Grit of Yorkshire" (*Quart. Journ. Geol. Soc.*, vol. 75., p. 251, 1919). H. C. Sorby, one of the greatest pioneers in microscopy as applied to stones, attributed as far back as 1859 the coarsely granular Millstone Grit to the destruction of granites and various types of quartzite. A. Gilligan, in his researches, which are as yet limited to Yorkshire, has been fortunate in finding pebbles as much as six and even ten inches long; these were probably brought into the grit entangled in the roots of floating trees.

Granite and compact granitoid igneous rocks are represented. A peculiar feldspathic and chloritic schist is recognized as undoubtedly coming from the Blair Athol district, 120 miles to northward. The granitic material differs from that of the Lake District, and also from the granites of Galloway, since these contain sphene, a calcium titanate and silicate which is absent from the grit in Yorkshire.

Examination in polarized light (p. 19) shows that the granite which furnished the grains was deformed and in part milled down by earth-pressures. Metamorphic schists formed part of the region of supply. The author concludes "that the only possible area lay still farther north, in what is now the North of Scotland, and its extension lay east with a larger Scandinavia, thus forming part of a great continental land, the limits (northern and western) of which it is not at present possible to define."

He points out that his detailed research thus confirms the views of previous authors, and he provides a map showing a great river running down the North Sea region, receiving tributaries from the Scottish highlands, and forming a handsome delta in Yorkshire and the English midlands. Here it laid down deposits with an average thickness of 1,000 feet, and it abutted on an east-and-west ridge jutting out from central Wales. This land-mass seems to be necessitated by the absence of marine Carboniferous strata in the central English midlands (see A. J. Jukes-Browne, *The Building of the British Isles*, Fig. 23, 1911). We should like to go farther, and regard A. Gilligan's delta as merely the western lobe of a great coastal plain, laid down by many such rivers from the north. The Coal Measure forests established themselves on the land thus built out into the sea, and subsidence allowed marine shells from time to time to mingle with the drifted stems.

A. Gilligan, observing the freshness of the feldspars in the grit, pursues his enquiry into questions of Upper Carboniferous climate. Enough has been said for our present purpose to illustrate this aspect of the study of stones.

In the field, the robust material of our native millstones has a fine effect upon the landscape. The scarps of the Roaches, four miles north of Leek in Staffordshire, and of Mow Cop in Cheshire, are due to the resistance of its edges. At the latter place the grains are cemented by barytes, barium sulphate, a not uncommon feature in the midlands. This white cleavable mineral can easily be distinguished from calcite by its far greater weight; it is insoluble in hydrochloric acid, and yields its sulphur, like gypsum, to the ingenious worker with the blowpipe. The dust of it, scattered through a bunsen gas-flame, produces the exquisite yellow-green colour due to barium.

The grits in Derbyshire and in the moorland country to the north stand out in terraces rivalling those of the underlying limestone. Again and again, some relic of them on the highest crest shows how they for long ages acted as a preserving cover. The plateau of the Peak in Derbyshire, with its vertical edges, is a survivor of the crown of the arch that once overlay the limestone of the dale-land. West and south of Sheffield, the Millstone Grit has been worn away; but it remains on the back of the Pennine fold for some thirty miles to northward. Even below it, in this northern district, serviceable coal-seams may be found; in the south, where more purely marine conditions prevailed in Lower Carboniferous times, the Millstone Grit is aptly styled the "Farewell Rock" by miners.

Many millstones in the stone age of flour-milling were, however, imported into England. These came from a completely different kind of rock, the *meulières* of northern France. When cycling through the forests east and south of Paris, in days that seem to have

passed away in a whirl of high explosive, we may have noticed the sharp edges of the stones used on the rectangular meshwork of small roads. Gathering these from wayside heaps, we found them unscratchable by the pocket-knife, and often cavernous with hollow moulds of shells. The form of the interior of the shell is frequently preserved as a cast, and the whole stone is formed of grey or brownish flint. Here and there small globules with spiral markings round them catch the eye. The traces of shells are those of molluscs living in fresh water, and the globules are casts of the seed-receptacles of the freshwater alga Chara. These "oogonia" in the living plant have long cells coiled round about them, which are recorded as spirals on the siliceous casts. Chara lays down calcium carbonate in the walls of its cells, and thus contributes to the deposits of fine-grained limestone that are often called freshwater "marls."

The *meulière*, in fact, is a lacustrine limestone the groundwork of which has been replaced by flint. Possibly the silica was derived from the frustules of diatoms, minute plants allied to algae, which abound in seas and lakes. The shells of characteristic freshwater molluscs, such as Potamides, Planorbis, and Limnaea, escaped alteration, and were dissolved after the flint was formed. Hence they appear now as hollows between the flint that represents the calcareous mud around them and that which occupied the place of the animal after death. We may remember moulds of this kind in the marine sandstone of our Edge (p. 30), and also in the Cretaceous flints of English downs (p. 100). The irregular pores in some of the millstones from the Paris basin may represent portions of the calcareous

mud that was never adequately replaced by silica. The rock owes its reputation as a millstone to its being minutely cavernous and also harder even than steel.

Alexandre Brongniart (*Traité de Minéralogie*, vol. 1., p. 322, 1807) describes the varieties of *meulière*, and says that at La Ferté-sur-Jouarre the bed was sufficiently thick for the stone to be cut in the form of a cylinder. Lines were then marked round this block, wedges of iron were driven in along them, and two or three millstones (*meules*) were split apart from the same mass. At Pacy-sur-Eure and Les Molières, the millstone was built up of squared blocks, bound round with an iron band.

In his *Description Géologique des Environs de Paris*, first drawn up with Cuvier in 1810 (second edition, pp. 56 and 274, 1822), Brongniart gives many details of the occurrences of *meulières*. The best stone contained numerous small cavities, but showed no trace of organic remains, and a good millstone two metres in diameter, with abundant small pores (styled *frasier*) evenly distributed, fetched 1,200 francs. *Meulières* containing casts of freshwater shells were worked at Cinq-Mars-la-Pile, on the Loire below Tours, and were exported even to America. One variety, for causes unexplained, was known as *œil de perdrix*. In the same volume, Brongniart's son, Adolphe Théodore, acutely describes the remains of Chara, occurring as internal casts in the millstone-rock of Montmorency.

The millstone beds near Paris are part of an extensive series of lake-deposits of Oligocene age, a period when the sea had been almost driven out of France, and when the broad plateau-lands of the north were already much like those of the district in modern days. Numerous

lakes, however, filled the hollows of the land, and the light-limbed mammals loved of Cuvier, precursors alike of the rhinoceros and the horse, came down to drink at their shores through woods that were still almost tropical. These fascinating creatures roamed no doubt also into England, and as far as the fertile Cainozoic country stretched, a land of loams and pleasant pastures, hiding away the barren substance of the chalk, and with here and there a palm-fringed inlet spreading from the southern sea.

In Miocene times the Paris region became still more definitely terrestrial, though the sea flowed for a time into the level lowland of Touraine. The end of this period set limits to the Oligocene loams and to the *meulières*. The crumpling of the Alpine chains sent a groundswell, as it were, north-westward; and the present ring of chalk was upheaved, from which the Cainozoic beds were gradually but persistently washed away. They were preserved, however, in the central basin, and on these lands Paris rose.

And now for a third type of millstone; to reach it we must enter the Carpathian ring. Here among the inner foothills is the *Mühlsteinporphyr* of German authors, the "millstone-porphyry," quarried in a volcanic highland some sixty miles north of Buda-pest.

When the Alpine movements that marked out the lines of modern Europe reared the Carpathians (as they reared the Chalk) towards the close of Miocene times, the basin of Hungary remained as a sunken area within the grand curve of the new mountain wall. Between the basin and the crumpled rocks of the range, volcanoes broke out on lines of weakness, and for a long time

rivers descended from them into a sea communicating with the east.

When this sea became drained out by general uplift its place was taken by lakes and finally by the Danube, which worked its way down against the continued rising of the ground, excavating the Cainozoic strata, of the lowland. The tributaries from the north kept pace, and in consequence cut deep valleys in the volcanic upland. The lavas, and even the crystalline rocks below them, have thus become exposed on jutting crags and on the walls of picturesque ravines. Oak and beech and birch have clothed the upper slopes, and the local magnates, while owing a general allegiance to the Hungarian king at Buda, found the country advantageous for self-assertion, and built their towered castles on the relics of volcanic cones.

In this romantic country rich silver and copper ores have been developed, which made Schemnitz (Selmeczbánya) a centre of attraction and instruction for miners from all parts of the world. The organization of the mines in recent times was largely Magyar ; but the workmen came from Saxony and from the Slovak highland. It remains for those who prefer national separation to international federation to draw in these troublesome years a just frontier through the hills. In the delightful valley of the Garam, inhabited by a simple and generally Slavonic folk, the millstone-porphyry is only one of many interesting problems.

The lavas poured out here in Miocene times were very often *rhyolities* (" flow-stones "), so called on account of their showing fluidal structure in perfection. These rocks are rich in silica and poor in iron, and are viscid when in a molten state ; their sticky flow leads to the

stretching out of parts already tending to become crystalline, and to the production of contorted sheets and bands of duller matter, with more glassy layers. the true uncrystallized ground, between them. Even when the whole has become compact and stony, this flow-structure may remain conspicuous. An admirable representative, a rhyolite with vertical flow-structure, occurs in the little circular vent of Cloughwater near Ballymena in the county of Antrim.

Obsidian, an analysis of which is given on p. 63, is the most glassy type of rhyolite; the Hungarian millstone-porphyry represents the other extreme, where slower cooling allowed the rock to lose nearly all its glassy character. Beneath a centre of rhyolitic outpour ing, we may presume the existence of a cauldron the contents of which will ultimately give rise to granite, as it cools through long ages underground (see p. 62).

West of Schemnitz, if we have pushed up over the divide, we may descend by the groove of a streamlet to Hlinik on the Garam, and in a few kilometres we meet every type of rhyolite. A hill of glass projects at Skleno, like that dreamed of in Celtic tradition—and were not the Celts a central European race? Then we have rhyolites with beautiful stony spherules in them, the "spherulites" of geologists, sometimes showing both radial and concentric structure; these are concretions put together in the attempt of the glassy rock to become crystalline before it cooled. Other types show spherulites that sent out rays and arms, which have been compared with the "pseudopodia" of protozoan animals, as if they were anxious to hurry up matters and to make a fair show so long as the temperature allowed. In others, the spherulites crowd

against one another, until their surfaces actually meet, converting themselves into polygons, so that the rhyolite becomes dull and stony throughout. The Hungarian millstone-rocks have sometimes avoided the spherulitic stage, and small crystals of feldspar and quartz show a gradual approximation towards granite.

All these rocks are pale in colour. The obsidian type is a black glass merely because light passes into it among a multitude of hair-like beginnings of crystals, which give it a dark tint throughout. The millstone-rock is commonly pinkish, and its essential value lies in its hardness, its compactness, and the numerous small irregular cavities that it contains. These were produced by the escape of vapours from the cooling lava, or in part, as von Richthofen thought, by the action of hydrofluoric acid among the volcanic emanations. They are often beautifully lined with chalcedony, rock-crystal, and amethyst. It is interesting to note how the silicification of limestone in France and the consolidation of an igneous rock rich in silica in Hungary have furnished in different ways the cellular characters required of a millstone.

One of the most detailed studies of these sub-Carpathian rhyolites was made by the French mineralogist, F.-S. Beudant, in 1818 (*Voyage Minéralogique et Géologique en Hongrie*, 3 vols., 4to. and an atlas, 1822). He translated the German name for the millstone into *porphyre molaire*, and describes a large industry spreading from the quarries of Königsberg (Ujbánya), an old town above the west bank of the Garam, throughout the larger part of Hungary. Beudant worked before the days of thin sections, which later writers have used so effectively in researches on the igneous rocks of Hungary;

but he noted the development of well crystallized quartz, feldspar, and small flakes of dark mica, in the compact pinkish or greenish ground, and determined almost all that could be known about the general structure of the rock.

Beudant's travels reveal an excellent combination of scientific observation and enjoyment of the country. He was not to be deterred by ungenerous jealousies, such as now lead neighbouring races to speak evil of one another; and he is the author of at least one memorable phrase, "la manière d'être reçu dépend beaucoup de la manière dont on se présente."

Some day Europe will again open up its roads and its byways to the traveller. Some day we may seek again the hill of glass and the valleys of the millstone-rock. The white-coated Slovak peasants will give us courteous greeting as we pass; and, when the last glow fades from the Calvary high upon the crag, the lights of little wayside shrines will once more guide us through the doubtful darkness of the woods.

CHAPTER XVIII

A STONY LOAM

THE first geological maps of the British Isles were really soil-maps. Their object was to show the sort of land on which agricultural pursuits depended. In days when overseas traffic was limited by the chances of the winds, and when colonial wheat-fields were still the property of unreceptive and prolific heathen tribes, a knowledge of the home lands of the homeland appealed to the members of intelligent agricultural societies. When William Smith observed in 1817 that " the search for a fossil may be considered at least as rational as the pursuit of a hare," he found a response among country gentlemen who already knew the qualities of soil.

In central Germany and in Scotland, where crystalline rocks were more familiar than in England, the mineral aspects of geology claimed most attention. " Geognostic " maps were constructed, and mere superficial deposits seemed of less account. By the middle of the nineteenth century, the attractions of mineralogy on the one hand and of palaeontology on the other threw the layer of the earth's crust on which we live still more into neglect ; and even at the present day " agricultural geology " is commonly held to be a smattering of just as much geological lore as a university don thinks that a

farmer's boy might reasonably know if he ventures on a public examination.

Yet the soil is one of the most remarkable of rocks. It may result from the decay of a single predecessor, or from prolonged natural processes of mixture. A uniform soil, like a pure-blooded nationality, responds little to the call of external cultivation. But, whatever its characters, the soil is probably, for all but miners and nomads, the most important asset of a district. It is the tractable rock that covers the intractable ; the rock that receives the sunlight and the rain, and provides a home for countless living things. The soilless lands of north-west Canada may please the eye of the mineral prospector ; but he imports his food in " cans " from the lakeside towns or Manitoba.

The very incoherence of soil is not a mere accident, but a property, and one that varies greatly under conditions of moisture or of drought. The soil reacts to climatic influences ; the soil, considered as a rock, links common stones with the atmosphere, and the dead dust of the earth with the continuity of life.

Air and uncombined water make up half the soil. If it rests upon the rock from the decay of which it is derived, we find as we dig through it that it becomes more compact and more distinctly stony (Fig. 20). Vegetable matter forms less and less of the soil-substance ; from a darkened condition it assumes the colour of the underlying rock ; and ultimately we reach the granite, or limestone, or slate, as the case may be, the presence of which is alone recorded on the so-called " solid " maps of Geological Surveys.

" What sort of soil have you here ? " we ask of Farmer Welland, who is watching his new tractor ploughing over

the fourteen-acre field. The young engineer from the Joyce-Ryde Motor Company of Thrapston is standing near him, giving him the latest practical advice. Farmers are not found leaning over gates nowadays, with straws in their mouths, waiting for the crops to show above the ground. It is doubtful if they ever did so, apart from the cartoons of jealous townsmen. For, generation after generation, they have worked the soil and watched its changes, have enriched it with the roots of clover or compacted it with the treading of the sheep, until they almost feel that they have made it; the rough hill-pasture has become a cultivated land. But the essential soil, still crumbling from the rock-decay, is the same as that with which their fathers dealt, right away back to the days of wooden ploughs, and beyond that again to prehistoric ages, when neolithic pioneers of culture turned up the earth with pointed sticks.

"What sort of soil?" echoes the farmer; "just a loam. You may call it a stony loam, but it's a good loam all the same."

It certainly contains a good many stones, and these show considerable variety. In between them, however, is the serviceable fine-grained matter that concerns the growing plant. Any soil may be conveniently divided into its "stones" and its "fine earth." For this purpose, a sieve is commonly selected that has circular holes two millimetres in diameter. The "fine earth" is what passes through this sieve.

This conventional gauge is a good one, since perforated zinc is easily obtainable with holes exactly of this size. A zinc sieve six or eight inches (two decimetres) across can be made by any tinsmith—if tinsmiths still are working—and may be floored with the

proper perforated zinc. The use of accurately made circular holes leaves us in no doubt as to the larger limiting size of the particles that come through. An ordinary sieve with crossing wires gives us square holes, that is, holes measuring less along their sides than along their diagonals. This allows the fine earth that comes through to include coarser fragments, and to be somewhat larger in amount when compared with the whole quantity of soil examined. In fact, a square hole measuring 2 mm. in the side has a diagonal measuring 2·83 mm.

In separating the stones from the fine earth, water must be used, since the more minute material clings closely to the stones. If fine earth is required for experimental purposes, and its quantity in relation to the soil-sample is not the point to be determined, the original sample, collected in a bag in the field, may be dried, its clots broken up with the fingers, and a sufficient amount of fine earth may be procured by simple sifting. The stones should be well washed in all cases; but there is here no need to keep the washings. The coarse material, dried upon the sieve, is now clean and ready for examination.

This coarse portion of the soil will give us good preliminary suggestions as to the character of the subsoil (p. 229). If it is fairly uniform in character, it will indicate the underlying rock. Conclusions on this point, however, should be verified by digging deeply, or even by the use of a soil-auger, of which various forms are now available.

For determination, it will often be necessary to break the stones. A small block of iron for an anvil is much to be recommended. It can be kept clean and is far better than a doorstep, the use of which, moreover, raises


Fig. 19. The Spirit of the Soil. Derbyshire.

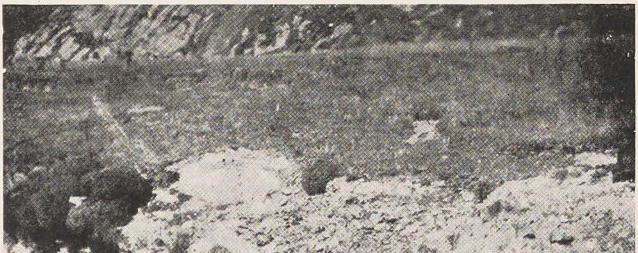
Fig. 20. Soil, Subsoil, and Coherent Rock. Slate, Valencia Id., Co. Kerry.

To face page 228.

domestic altercations. Any hammer with a flat face serves ; it is unnecessary to send for the professional tool of the geologist. Care and skill, however, are required, since the small stones of a soil are often very stubborn, and their fragments fly off to the dark places of the earth, or else, by sheer contrariness, seek the light by passing through a window. A bottle of hydrochloric acid, with a dipping-rod, should be at hand for testing.

The variety of stones from the surface of a loam is often highly interesting. White lumpy quartz-fragments from veins, slightly rounded in the wear and tear of Nature before they rested in the soil ; bits of sandstone, brown and crumbling, passing into a healthy sand when the ploughshare cuts across them ; bits of limestone, perhaps, ready to yield calcium carbonate in solution when the soil-waters trickle over them ; here and there a fragment of granite, in which the characteristic plates of mica gleam. Shales, unless the underlying rock consists of shale, will not be so well represented ; they have been reduced by long weathering to their original condition of plastic clay, and their particles must be looked for in the fine earth that passed through the sieve or was washed away.

In making a drain, or occasionally in deep ploughing or trenching, or even, as above suggested, by digging with a spade to complete our study of the soil as a part of the earth's crust, the *subsoil* may be reached. For convenience, we may say that the soil is the layer eight inches (twenty centimetres) deep that is turned over by the ordinary plough. Below this is the subsoil, till we come down to coherent rock (Fig. 20).

The subsoil may be either " sedentary " or " transported." It is usual to apply these terms also to the

soil; but, if we accept the above definitions, almost all soils have subsoils on which they are sedentary, and our interest is directed to the relation of the subsoil to the bed-rock on which it rests. In the case of a sedentary subsoil, we soon come across, as we dig downwards, flakes of stone between which the soil-material lies; as we said at the outset, the finer earth in the interstices of the subsoil-stones will have a smaller quantity of decayed vegetable matter in it; it will be, as agriculturists say, not so "humous" as the upper soil. A humous soil is one rich in "humus," the dark material derived from rootlets, and from stems and leaves that have got worked in, a mixed substance of vast importance in the supply of nitrogen to the crops.

Roots have been thrust down from above into the subsoil; they have, indeed, commonly helped to make it by wedging apart blocks of the underlying rock; but we soon pass from the zone of vegetable influences to that representing ordinary rock-decay. By the action of soaking waters, the bed-rock may be decomposed and crumbling for many feet below the surface; but in most cases there is a fairly rapid transition from the loosened material of the subsoil to the ancestral rock.

In the case of a transported subsoil, the junction of subsoil and unbroken rock may occur at a smooth surface worn by river-action or by glacier-ice. The alluvial infilling of a valley represents transported material. The boulder-loam that covers much of the British Isles is similarly a transported subsoil; it was left behind on the melting of great glaciers which had gathered into themselves all manner of loosened rocks, and at the same time transferred pre-existing soil-caps from one part of the country to another. A transported

subsoil may be hundreds of feet thick, and may represent the scouring of an extensive district. Its variety of mineral matter offers chances for a wide range of cultivation.

The stones, provided that there is fine earth also, do not greatly harm a soil. They " grow " at the surface, as every farmer is assured. What happens, of course, is that in our climate the fine earth is washed by rain down any convenient slope, and also into the interstices of the subsoil. In semi-arid countries, there is far less difference between the surface-layers and those below ; but with us the artificial bringing up of the subsoil to mingle with the soil may render the latter unpleasantly compact and sticky. The return of the fine earth to the surface by the activity of worms is the great feature of old pastures. The stones here become buried, and an extraordinary difference is observable in the soils of two fields side by side, one of them frequently tilled and the other, equally exposed to the wash of rain, but protected by grass through many years.

The stones, if not more than two or three inches long, may even be an aid to cultivation. When the sun is shining, they become heated more quickly than the fine earth round them, since the latter is usually moist, and the temperature of water rises very slowly in response to heat supplied to it. Stones thus warm the soil. They also prevent undue loss of water by evaporation. When a piece of slate, for instance, is lifted in the morning from the tilled surface of the field, it will be found to be damp upon its under side.

Cracks, moreover, often occur between the stones and the fine earth when the latter shrinks on drying, and passage-ways are thus opened up for the descent of rain

into the soil. The supply of both air and water to the roots of plants, and to the minute organisms that assist their growth, depends on the nature of the soil-passages.

It is clear that a plant will not flourish on an absolutely bare and uncracked rock. It must have some space into which to thrust its roots. It must at the same time be fed. A large part of its food-supply will be given to it by solutions in the soil, and these solutions must be weak, that is, there must be plenty of water and very little dissolved material in them. The texture of our stony loam becomes, then, a matter of considerable interest. Farmer Welland has called it a good loam; for him it is not too "light" and not too "heavy."

In what does soil "lightness" or "heaviness" consist? In the amount of very fine material in proportion to the fine earth as a whole. Not only this, but something in the chemical nature of the very minute soil-particles promotes the essential clayiness of clay. A stiff clay is practically impossible to till; and when tilled its physical properties are inimical to the growth of crops. Hence clay lands are commonly grasslands; loams are tillage-lands.

Minute particles of quartz form a sticky mass when wet; but this falls again to pieces, to a mere fine sand, when it dries. Minute particles of flaky silicates, such as kaolin, the common product of the decay of feldspars, or chlorite, derived from aluminium-iron-magnesium silicates, produce a similar stickiness; but the aggregate holds together and shrinks obstinately when it dries. This is an essential property of clay, though other substances seem clayey enough when wet and are then hard enough to till.

A soil that is "light" has not too much of this clay-

substance in a very finely divided state ; a soil that is "heavy" dries into compact clots, with shrinkage-cracks between them, and rootlets may be actually torn by the force of the contraction. The clots break up again when wetted into a plastic mass that is very difficult to work. Hence in recent years, in order to understand the characters of a soil, it has been customary to separate, by various processes of washing and decantation, fine earths into a number of grades, such as particles between 0·05 and 0·01 mm. (one-hundredth of a millimetre) in diameter, or between 0·01 and 0·002 mm. (two-thousandths of a millimetre), and especially to ascertain what percentage of the fine earth is smaller than the latter figure.

Beyond noticing the general coarseness or fineness of grain, we do not analyze our ordinary rocks in this way. In our stony loam, however, we have a rock consisting of loose particles, composite or simple in their mineral constitution, and the most important things in a soil are the sizes of these soil-grains and the diameter and disposition of the interspaces between them.

The water in the soil, and the air in the soil, which is quite as important, move through these narrow interspaces. If we stand a glass tube with a narrow bore in a bowl of water, the water will creep up to a certain level within the tube. If the bore is wide, the rise of water will be scarcely noticeable ; if it is very narrow, the rise will be very striking. It is, in fact, inversely proportional to the diameter of the bore. The inner surface of the tube pulls up the water against the natural force of gravity that pulls it towards the centre of the earth, and against the pressure of the atmosphere that presses on it through the upper end of the tube.

The surfaces of soil-grains similarly draw the water over themselves through the minute passages between them. Water thus spreads through the fine earth of the soil in all directions. The movement is called *capillary*, from the Latin *capillus*, a hair, on account of the hair-like narrowness of the passages in which it is effective. Capillary movement downwards is assisted by gravity ; capillary movement upwards is against gravity, and goes on in a soil with extreme slowness when the passages are very small.

When rain has penetrated into a soil, the upper layers may soon become dry by evaporation ; but the damper lower layers, and the subsoil, return water to the surface by capillary movement. It is important that the growing crop should thus acquire water in days of drought. Hence a soil with very fine passages, which enable water to rise from a considerable depth, may not be so desirable as one with larger passages, so long as these are still of a fair capillary grade. In the former case, the creep may be so slow as to be unserviceable.

A Swedish researcher, A. Atterberg, has shown that the grains that provide interspaces of a satisfactory size, neither too wide nor too narrow for useful capillary action, are about 0·02 mm. in diameter. A soil the fine earth of which possesses a good proportion of particles of this grade, without much finer matter to choke the passages, will possess efficient capillarity from the farmer's point of view.

But our loam must also be able to pass water through it from above. It must drain well, since the water supplied by capillary rise is not that which is most healthy for the plant. The fresh supplies from the falling rain, bringing with them fresh gases from the air, are needed to keep the

houses of the rootlets wholesome. From this point of view, the passages between the soil-grains should be large and open, yet not so open as to leave the soil without retained water.

Here again texture becomes an important consideration. A clay, even when freely drained below, may retain too much water and pass it through very slowly. Capillarity of course helps drainage by acting in a downward direction; but here again the small size of the particles may render the movement ineffective. It may be necessary to assist the descent of the water, and to lighten the whole soil by artificial means for working with the plough.

The old farmers discovered that stiff clays could be lightened by adding finely divided limestone to them. The calcium carbonate of which marine shells and the hard parts of many seaweeds are composed served equally well if mingled with the soil. In the county of Wexford a shelly deposit underlying the less tractable superficial clays was dug up and spread upon the fields. The "marl-pits" from which this material was obtained are still to be seen throughout the southern part of the county. Latterly, burnt lime from the kilns has been substituted generally for limestone; but this is not on account of any virtue in the oxide. The lime is convenient, because it easily powders down; but it becomes promptly converted into carbonate by the natural waters present in the soil. Whether we use lime or limestone, it is calcium carbonate that goes into solution in these slightly acid natural waters, and this salt destroys excessive clayiness by altering the texture of the soil.

As we have said already, clayiness in a fine earth is

determined by the proportion of particles about 0·002 mm. in diameter or less. The botanist, Robert Brown, showed in 1827 that particles of this small size, even though inanimate, are in a state of constant movement when immersed in water. Since his time, what is justly called " Brownian movement " has become a fascinating subject of physical research. There seems no doubt that the motion is due to the buffeting of still smaller particles, the ultramicroscopic molecules of the water, on the bodies that we can just perceive with high powers of the microscope. This in itself would not keep the visible particles apart. They might be knocked against one another and might adhere to one another by attraction. But mineral particles of the same kind are charged with the same kind of electricity, and those in ordinary soils are almost all negatively charged. The fact that they carry the same kind of charge causes them to repel one another.

We must remember that this is no explanation, and no one can tell us the inner meaning of these terms. Some words, however, must be used to express the facts ascertained by thousands of experiments. The particles similarly charged fly apart when they approach—a phrase that is lucidly Hibernian—and cannot clot together and escape from their battering surroundings.

Larger particles are hit by so many molecules at once on all sides that they remain still, or can gently sink down by gravitation. The tiny ones are so near to molecular dimensions that the buffet given on one side may be distinctly greater than that given simultaneously on the other. Though they tend to concentrate near the bottom of a liquid column, those near the bottom never touch it. They cannot even pair off, like the

condemned lovers smitten by the air in Dante's second circle.

Anything that will reduce or counterbalance their electrical charge will allow the Brownian particles to join one another and to form composite and larger grains. Directly this occurs, the whole soil is lightened. The texture of its fine earth is coarsened, and larger grains imply larger passages between them. The total pore-space may be considerably reduced ; but the individual pores are opened out. The conditions for the circulation of fresh air and water, and for working the soil with implements, are improved.

This is what calcium carbonate in solution brings about. The minute soil-particles are caused to "flocculate," that is, to form groups, and extreme clayiness is destroyed. A great many other salts in solution, such as gypsum (calcium sulphate) have the same effect ; but limestone or burnt lime is nearly always available, and calcium carbonate has other beneficial influences, of a chemical nature, which justify its general use.

Our stony loam, then, regarded as a rock, is unlike other rocks in deriving much of its interest from the interspaces between its particles, and these we can vary at our will. Even if we include the solid stones in the soil-sample, we may find that the interspaces in a litre of soil occupy half a litre, or 50 per cent. of the whole bulk. In these interspaces, actions are always going on between the included air and water on the one hand and the grains of decomposable minerals on the other.

Feldspars with their potassium or calcium, dark micas with their potassium, magnesium, and iron, augite with its calcium and magnesium, apatite with its much desired

store of phosphorus, slowly yield these substances to the soil-solution in the form in which they can be utilized by the growing plant. Calcium carbonate in solution exchanges its calcium for the potassium of silicates and for the iron and aluminium that are stubbornly combined in certain phosphates. The very surface of the clayey soil-particles absorbs valuable ingredients from the soil-solution, and these are given up to the rootlets, or liberated when required by a process of chemical exchange. In this way, as hinted above, " marling " the land has not only physical results, but affects the chemical character of the soil-solution, and renders a certain amount of potassium and phosphorus available that otherwise would not have reached the growing crop.

Furthermore, the air in the improved interspaces of the soil encourages the multiplication of minute organisms, the most important of which are the " nitrifying " bacteria, which require plenty of oxygen for their processes of growth. Are we to regard these organisms also as constituents of the soil? If we do so, they further emphasize the difference between our stony loam and the other rocks that we have considered, which alter mainly under the influence of inorganic chemical attack.

The living bacteria certainly contribute to the chemical characters of a soil. One series promotes decay in organic matter and liberates ammonia. Another bacterium produces nitrous acid from the ammonia, and gives rise to nitrites. This allows another bacterium to form nitric acid by a further process of oxidation, and the nitric acid combines with calcium compounds and other soil-constituents to form nitrates. The nitrates go into solution, and from them the ordinary crops derive

nitrogen, in addition to what they get from ammonium compounds. Moreover, certain bacteria, which can exist a metre deep in the subsoil, withdraw nitrogen directly from the air and help to work it up into vegetable material, especially in association with the nodules of the roots of leguminous plants. Here we are we going beyond the limits of even an unconventional essay in geology. The illustrious Linné or Buffon might approve ; but we must hand the reader over to authoritative works, such as those of A. D. Hall and E. J. Russell (*Standard Cyclopedia of Agriculture*, vol. 9., p. 99, and elsewhere).

We set out in the hope of showing that our stony loam is a highly complex substance, and quite as attractive to the petrographer as " Katzenbuckelite " and " Hypidiomorphic texture." If the soil seems to us the end of the long history of a rock, and the decrepit product of its old age and decay, it is all the same the medium for new and vigorous growth.

Through plants and herbivorous mammals, the soil as a rock-mass is the foundation of our human life. Farmer Welland, who has fostered the plants and tamed the errant herbivores, knows this far better than the geologist, and we shall gain greatly from his company in the *Drovers' Arms* at noon. Through the open window, fold on fold, we view in stimulating sunlight the rich brown tillage of the fields. It is the appeal of mother-earth to the understanding of her sons.

CHAPTER XIX

THE PORPHYRY FONT

"RUBET Porphirites in Ægypto," says Cesalpino, in his *De Metallicis*, 1602, and the words have a fine sound in the opening of Liber secundus, cap. xvi. We never think of porphyry except as a polished stone; the antique porphyry of to-day was the common porphyry of the Romans, a rare stone made popular by them and brought to general knowledge from their conquest of the east.

To this day the name suggests something opulent, and at the same time something lasting. A porphyry font, a porphyry column—these may be found in museums, but surely were the spoils of palaces. The colour, a deep purple red, attracts but rests the eye; the cold hard surface has survived the dynasties of kings.

The Egyptian monarchs wrote their lives in architecture. The same taste or lack of taste that leads visitors from Pittsburg, from Barmen, or from Burnley to scratch their names on ancient monuments led the kings of the east to carve their personal records on the rocks. From natural sun-flaked slabs on the changeless routes of caravans, they turned to vast advertisement on the walls of temples and of tombs.

In Egypt their cartouches were reared aloft on obelisks, to greet the sun-god as he rose. The red granite of Assuan and the black basalt of Ethiopia—basalt itself is an Egyptian term—were imported down the Nile to adorn the delta with statues of domestic or colossal size.

Julius Cæsar and Marcus Antonius must have realized the Levantine love of stone in the luxurious halls of Cleopatra. Cleopatra's daughter, "the moon-girl," must have carried it with her to Mauretania, where her husband Juba proved himself an amateur of art. Yet one of the most splendid stones of Egypt was scarcely known to the Egyptians.

It lay in a desert region (Lat. 27°12′ N. and Long. 33°15′ E.) about 100 miles from the Nile and twenty-two from the Red Sea, and the vase made from it and found in recent years at Ballas north of Thebes was possibly worked from a boulder in local conglomerate (see W. F. Hume, in "Topography and Geology of the Eastern Desert of Egypt," Geol. Surv. Report, Cairo, p. 86, 1902).

Among the tracks that crossed this desert from the habitable valley to the Red Sea coast was one from the great bend of the river near Dendera to the old port of Myos Hormos. Qena now stands here on the Nile bank and communicates eastward with Qosseir. The north-eastern route from Qena, marked by a chain of wells, had to cross a tract where peaked summits of granite rise 5,000 feet above the sea. Branches led through this difficult region, and one of them selected a pass in the broken highland now known as Jebel Dokhan. When the Romans became overlords in Lower Egypt, their efficient and cultivated civil service opened up mines and quarries where the Egyptians

scarcely penetrated. Some member of the geological staff, when sampling the eastern granite, came upon the source from which the porphyry boulders were derived. Perhaps he noted the purple colour where wetted by the water of a well. His specimens received approval from his superiors, and were probably submitted to the Imperial Bureau of Mineral Resources in the capital.

A quarry was promptly developed, where slaves precluded the possibility of strikes; machinery was set up for moving massive blocks; and the road was improved to bring them to the Nile and so through Alexandria to the ships. Columns were worked at the quarries, and one, left uncompleted, lies to the west of Jebel Dokhan to this day. Fragments of porphyry along the track bear witness to the traffic in the stone; even the hollows in the mountain road were levelled up with porphyry.

The name of the stone was derived from *porphureos*, since Greek was the *lingua franca* of the delta, and it refers merely to the colour. The porphyry reached Rome about the time of Claudius. It was at once hailed as an enrichment of the paler colour-schemes of Greece; its associations, moreover, made it a welcome and a stately acquisition; authors and diplomats, discussing the bounds of empire, could halt before a slab and say, "When I served in Egypt——" Thenceforward, for inlaid pavements or massive vases, porphyry became almost a necessity where culture went with wealth.

Nero's sarcophagus, the gift of somewhat fatuous friends, was made honourable by its use; and the ashes of Hadrian, the illustrious traveller, were appropriately enshrined in a block of the imperial stone. In

the earth of Italian cities, amid the wreck of costly marbles, fragments of porphyry, cut and polished, are still gathered and mounted as memorials of the grandeur that was Rome.

The sects that divided Christendom vied with one another in the decoration of their churches, and thus a few artisans may still have been working on the porphyry when the Arab wave broke the empire of Heraclius. Was the name Jebel Dokhan, " mountain of smoke," derived from the last despairing signal-fires? The wave swept westward, and the quarries remained idle for twelve hundred and fifty years. English travellers, notably John Gardner Wilkinson in 1833, rediscovered and described them. Fifty years later, G. Schweinfurth made a careful archæological survey of the district; and W. Brindley, well known for his enterprise and research as an importer of artistic stones, revived the industry at Jebel Dokhan in 1887. His paper on " The Ancient Quarries of Egypt " (*Trans. R. I. British Architects*, N.S., vol. 4., p. 5, 1888) contains sketches of the site, and a list of important sculptured work in which the porphyry was used. Since the opening of the present century, the Geological Survey of Egypt has explored the eastern desert (T. Barron and W. F. Hume, *op. cit.* above), and some corrections have been made in previous descriptions of the stone.

The porphyry proves to be one of a series of andesitic lavas of very ancient date. It is cut by other igneous rocks, including the granite of the district, which is older than the Cretaceous period. Andesites are so called from their prevalence among the outpourings of the huge volcanoes of the Andes; but they are an extremely common type of lava, intermediate between the rhyolites

(p. 221) and the basalts (p. 148), and containing some 60 per cent. of silica. The so-called "porphyrites" of the Ochil and other scarps in southern Scotland are altered andesites allied to those of Jebel Dokhan. Every type of andesite occurs in the Slovak uplands (Chapter XVII) and among the north Bohemian cones, except the original *porphyrites* brought by the Romans from the land that Cleopatra lost.

This "antique red porphyry," as it is now commonly styled, has been described by A. Delesse, Oskar Schneider, H. Rosenbusch, and others. Its conspicuous features are due to the scattering of small white crystals of feldspar and dark red crystals of hornblende through a deep pink-purple ground. As explained on p. 51, the structure has given rise to the adjective "porphyritic," now applied to any igneous rock in which larger crystals lie amid more fine-grained matter.

The feldspars are sometimes tinged with pink, and the microscope shows, at any rate in the section now before me, that this is due to small inclusions of the dark red hornblende. The mineral that colours the ground occurs through the rock as flecks and prisms, and the latter, in the form of needles, sometimes fill cavities as a delicate fibrous mesh. The same mineral has developed in the altered hornblende. It has been identified with thulite (a manganiferous zoisite) and with withamite (a manganiferous epidote); possibly both these minerals occur. In any case the glory of the stone is due to the presence of manganese.

Very small quantities of a colouring substance suffice to produce brilliant effects in minerals and in rocks. A pink feldspar from the antique porphyry analyzed by A. Delesse (quoted by H. Coquand, *Traité des Roches*

1857) yielded only 0·60 per cent. of manganous oxide (MnO), or 0·46 per cent. of manganese. This was probably concentrated in hornblende included in the feldspar.

On p. 167 we mentioned the mineral epidote at Moose Mountain. This is a silicate that may be concisely written and committed to memory as $HCa_2(Al,Fe)_3Si_3O_{13}$, or structurally as $Ca_2(AlOH)(Al,Fe)_2(SiO_4)_3$. It arises where decay sets in among silicates containing calcium, aluminium, and iron, and the product is more handsome and more permanent than the minerals that have broken down. Common epidote is too hard to be scratched by a knife; its colour is a fine yellow-green; and large crystals, such as those sometimes found projecting into cavities and veins, have almost the character of gem-stones. In igneous rocks, from granite to basalt, epidote is common in granular patches, always, it seems, as a secondary mineral arising after the consolidation of the mass. In thin sections, it may be seen, associated with new granular feldspar, and sometimes with calcite, as a replacement of the substance of calcium feldspars and other minerals—a replacement that renders the rock harder and more resistant as a whole. Zoisite, with a higher degree of crystalline symmetry, is chemically an epidote devoid of iron.

The andesite of Jebel Dokhan contained manganese. This element was probably associated in the first instance with the aluminium-iron-magnesium silicates in hornblende; or it may have been imported into the rock during its decay. In minerals, manganese can take the place of both aluminium and iron without much disturbance of the crystal-form. Hence we may have among the silicates manganiferous varieties of

hornblende, epidote, or zoisite. The two latter are pink-red minerals.

The replacement of one element by another in a chemical formula looks easy enough; in Nature it means in the great majority of cases some alteration in the crystal-structure, and this is revealed by careful measurements of the external form. Where, however, the differences are slight and the general relationship remains obvious, two or more minerals are said to have equal forms, or to be "isomorphous." The question of "isomorphism" is of immense interest, as illustrating the relationships of the elements themselves, and an example appropriate to the case in hand may perhaps be mentioned here.

Manganite, manganese hydroxide, $MnO(OH)$, has a marked similarity in its crystal forms with göthite, iron hydroxide, $FeO(OH)$, and with diaspore, aluminium hydroxide, $AlO(OH)$. The three minerals crystallize in elongated prismatic forms of the same crystallographic symmetry, and the angles measured over the edges formed by the meeting of corresponding planes are similar. Here, for instance, are the figures, firstly for the larger angle of the prism, and secondly for two commonly occurring and geometrically independent planes:

Manganite	99°40′	147°9′
Göthite	94°52′	146°33′
Diaspore	93°43′	147°12′

Isomorphism is one of the pleasing bypaths that diverge from the trail of common stones. For the present, we must come back to the manganese compounds in the porphyry.

When the epidote-making phase was reached, a

phase that also produces zoisite, manganese was utilized, and a red flush spread throughout the rock. O. H. Little, of the Egyptian Geological Survey, who has given me very valuable notes, tells me that the other andesites of the district are dark green. The effects of manganese in the epidote-series at Jabel Dokhan can be illustrated from quite another region.

At St. Marcel west of Aosta in Piedmont—French names die out slowly in this valley—the schists of the Alpine foothills are exposed in a number of bold cliffs, cut by the Dora in its boisterous passage from Mont Blanc. The hills are rich in copper ores, and delightful rocks may be collected, in which pink garnet, glaucophane (a clear blue type of amphibole rich in sodium), and opaque golden-yellow copper pyrites are associated. In a schist of this Alpine series, an epidote containing some 10 per cent. of manganese has developed in small lustrous prisms. Its magnificent red colour is evidently due to the manganese—though the question of colour in minerals is full of obscurity and contradictions—and it has received the special name of piedmontite.

Piedmontites from other localities than St. Marcel have been analyzed, and the manganese-content of some is very small. That of the sub-variety withamite, known in the lavas of Glencoe, is only 0·1 (one-tenth) per cent. A trifling amount of colouring matter has given the richness of ruby to the reconstruction-products of the antique porphyry. Roses flourish in the fields of Farsistan; but " rubet Porphirites in Ægypto."

Side by side with the antique porphyry, for purposes of decoration, a green porphyry, known to old authors as an " ophite," was brought from southern Greece. Here more normal epidote is the colouring matter.

Greenish feldspars, much larger than those in the red porphyry, lie in a deep green ground. The touch of yellow in the epidote gives the rock a certain brightness, which is lacking in the rock of similar structure in Lambay, north of Dublin Bay.

The " Lambay porphyry " would be more considered were its rival not more beautiful. The feldspar is somewhat duller, and the quantity of epidote is more easily appreciated with the microscope than with the unaided eye. Here again we have a volcanic rock, which cooled in this case in an old vent of Ordovician days; and on the opposite shore the lava-flows, full of steam-bubbles, and the ejected igneous fragments are mingled with shales and shelly limestones that record the presence of the sea.

Andesites are a very common type of lava. The porphyritic varieties with conspicuous crystals that developed in the cauldrons of the earth are more likely to be found near denuded centres of eruption; but the tendency to crystallize that is shown in igneous rocks with only 60 per cent. or less of silica renders almost all andesites porphyritic. As the lava rises, the still fluid ground tends to re-dissolve the crystals; feldspars become penetrated by tongues and filaments of brown glass, and hornblendes are sometimes reduced to mere skeletons, in which the form of the crystal is represented by a regular arrangement of residual grains of magnetite. These are microscopic details; but they mean much in the history of a rock.

The right place for porphyry, however, is not in the coldness of petrographic classification, but surely in the halls of dreams. Tennyson knew this well; plain marble, even the whitest of Carrara, would not

have suited him for that vision of hot midnight, when all the garden lay at rest.

> "Now sleeps the crimson petal, now the white ;
> Nor waves the cypress in the palace walk ;
> Nor winks the gold fin in the porphyry font :
> The fire-fly wakens : waken thou with me."

CHAPTER XX

MISSING STONES

THE greatest of the missing stones is ice. Not so very long ago, it clothed half a continent with a stratum one thousand, two thousand, three thousand feet in thickness. It floats as a restless residue upon the Arctic Ocean, but has vanished from Dublin, Dresden and the basin of the Don. It remains in Greenland, controlled by the general circulation of the air ; but it is shrinking on the heights of Wyoming, and has long since passed from the plains of Illinois. The detritus that was held in the lower levels of the continental sheets remains as eskers, drumlins, and a general boulder-loam. The rock itself, the ice-stone, has vanished in the ocean and the air.

Here and there on the surface of our country we come on traces of vanished stone. The " sarsens " of the Salisbury plateau are relics of an early Cainozoic stratum the softer parts of which have disappeared. They are sandstones cemented to some extent by silica, and lie as loose blocks over a wide area of the chalk. A large number have been broken up by farmers as material for walls.

The most famous sarsens are those utilized in the

later stone-age or the bronze-age by the builders of Stonehenge, " the stones that hang." Trimmed and squared, they form the great trilithons of the temple. Sarsens are supposed to be named from the village of Sarsden near Andover, and they are also known, in this wide sheep-country, by the picturesque name of " greywethers." Scattered as they are over the downs, they represent a former extension of the sands that underlie the wooded lands of Hampshire and Bagshot Heath.

In Hertfordshire, again, a conglomerate of flint pebbles, set in sand cemented by silica, occurs in Lower Eocene strata. This is a very handsome rock, the flints being iron-stained in tints of red and yellow brown, while the cement is often white and glistening. Its resistance to decay has allowed numerous blocks of it to survive in the glacial deposits of counties to the east, and their abundance shows how large an extent of rock has disappeared that once acted as a cover to this particular zone.

The pebbles of flint in the Lower Eocene beds of Woolwich Common represent, as must be evident, the destruction of chalk between Late Cretaceous and Eocene times. It is interesting to reflect how many feet of chalk went to the formation of a foot of these closely packed and water-rounded stones. The vast extent of missing chalk is still more impressed upon us when we think of the irregular flints that form recent gravels throughout eastern and south-eastern England.

But not only here, for flints turn up in the most unexpected places. They abound in the glacial beds on both sides of the Irish Channel, where no chalk now lies nearer than the Antrim coast, and they increase

in size as we trace them southward to the beaches of the county of Wexford. Near Carnsore Pt., with their white surfaces and irregular forms, they look as if they had been dropped a few days ago from some chalk mass facing on the sea, perhaps a vanished Beachy Head.

On Inishbofin of Galway, and other storm-swept western isles, flints attest the former presence of the chalk, and they abound in material dredged from the floor of the Atlantic off the western Irish coast. E. S. Greenly in his *Geology of Anglesey* (Geological Survey, 1920) pictures the chalk as passing over Snowdon and Anglesey alike, and A. J. Jukes-Browne (*The Building of the British Isles*, 1911) had previously furnished a map showing the Late Cretaceous sea, in which the chalk was deposited, as flooding the Irish area from Fair Head to beyond the Shannon mouth. Greenly regards the present elevation of Snowdonia as due to gentle folding in Cainozoic times; the Welsh chalk would thus have been lifted to a level of danger and would have vanished all the more swiftly from the earth.

If we say that it has not vanished—that it went into solution and now forms limestone elsewhere, and that the shell-beds of the Paris Basin and the modern globigerina oozes are resurrections of the chalk—none the less the chalk itself is missing as a stone. We can realize what has happened when we stand at Chanctonbury Ring and look northward across the Wealden hollow to the downs of Dorking, a stretch of five-and-twenty miles; but do we realize the enormous loss of solid rock when we view, from the Beacon Hills of Stokenchurch or Calne, the back of the Cotswolds, with their clays and yellow limestones, emerging from under the Chiltern

scarp ? The eye can bridge the gap between the North and the South Downs, but where did the Chiltern edge come down again to earth ? The other side of the arch, together with that of the Jurassic strata of the Cotswolds, is now found in the county of Antrim, three hundred miles away.

The destruction of the cover of midland England, of Wales, and of the region of the Irish Sea, began in Eocene times; the flint-conglomerates have already shown us this; but a large part of the chalk that now is missing remained till a much later period. On its back the rivers began to run which now, within the Cotswold edge, appear only as "beheaded" remnants. There is little doubt that the Thames system once derived its waters from the upper Severn across a plateau of Jurassic and Cretaceous strata.

The basaltic lavas of the north of Ireland and the Inner Hebrides afford another impressive example of stone missing from our islands. From the west of Donegal to the coast of Down, and thence northward through the west of Scotland, dykes of dark basaltic lava, with the same uniform N.W. and S.E. trend, break across all the strata. Precisely similar dykes cut the chalk where it occurs within this area, and pass up through the overlying lavas, which are probably of Oligocene age.

These dykes represent the channels by which the lavas reached the surface, and it is extremely improbable that the flows emerged only where the plateaus formed by them now remain. The scarps bounding these plateaus above Carrickfergus or Limavady, the steps of terrace after terrace in the desolate lands of Mull, the outlying stacks of Staffa and Loch Bracadale, and

the superb cliff-faces on the Sound of Raasay, alike prove the enormous loss by denudation.

The inflow of the Atlantic in the Pliocene period is responsible for a portion of the former plateaus; but a large part of the loss was caused by ordinary surface-action on land where hardly a basalt pebble now remains. The missing volcanic stone parted in solution with its calcium, its magnesium, much of its iron, and much even of its silica, and the residue of the glowing lava-flows, which rivalled those of Kilauea in Hawaii, must be looked for on the earth as common clay. The cycle of decay and reconstruction, put forward by James Hutton a century and a half ago, seems nowadays self-evident when we search for missing stones. Yet it needed the touch of his philosophy, based upon inexorable evidence, to break the tyranny of what men thought with the logic of what men observed.

ENVOI

THE facts and figures quoted in these essays are merely a basis for new thoughts, and these thoughts the reader will himself supply. It is still sometimes made a reproach to scientific workers that weighing and measuring form the basis of their cumulative faith. The pursuit of common stones is merely one of many branches of enquiry that will sustain them happily under such an honourable charge. The neglect of weighing and measuring by the leaders of public movements in the past has not encouraged confidence in human intuition; nor can we look to miraculous interventions, like the riding of Jeanne Darc from Vaucouleurs, to save us from natural forces of which we boast our ignorance. But, above all, the path of scientific enquiries is the path of patience and of truth. It is eminently the path of peace; we look for those who will work with us, and not for those against whom we may raise a hand. If we achieve anything, it is because the leaders went before us, and we follow them gladly because we have comrades in the field.

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